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REPORT OF THE DEFENSE NUCLEAR AGENCY WORKING GROUP ON NUCLEAR RADIATION EFFECTS ON GROUND COMBAT UNITS (U)

September 1976

In-House Report for Period June 1975—September 1976

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

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This report summarizes the areas considered, findings, and conclusions of a Working Group convened in June 1975 by the Deputy Director for Science and Technology of the Defense Nuclear

... warfare and determine nuclear effects levels that are of operational significance on the tactical nuclear battlefield. The issues determined to be of major importance were the

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20. ABSTRACT (Continued).

impact of combined effects and the performance degradation of a unit as opposed to an individual, when exposed to various radiation dose levels. A radiation dose level of 3000 rads was determined sufficient to render a unit ineffective on the battlefield; units exposed to hundreds of rads will suffer militarily significant degradation within a few hours; and a few tens of rads is unlikely to cause any militarily significant degradation.

Although none of the information contained in this report is specifically addressed in any classification guide, the compilation of information may impact on future weapon military characteristics and employment. Divulging this information would not be in the best interest of the Nation and could cause increased activity in this important nuclear effects area.

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PREFACE

As an outgrowth of several earlier efforts and in response to a need for more definitive criteria for troop incapacitation from nuclear attack, a Working Group was convened in June 1975 by the Deputy Director for Science and Technology of the Defense Nuclear Agency. The Group adopted a charter along the following lines:

> *The Working Group was asked to examine plans, doctrine and scenarios relevant to theater nuclear warfare. From this examination, the Working Group was to recommend (or develop a rationale for the development of) nuclear effects criteria which have* <u>*operational*</u> *significance on the tactical nuclear battlefield. Particular attention was to be paid to those nuclear effects which can be used to blunt an armored attack. A thorough re-examination of the radiation criteria, in concert with other nuclear weapons effects, for incapacitation of combat personnel, including the degrees of incapacitation, as a function of the conditions of the particular combat operational situations was called for. It was considered desirable that deliberations should prove helpful in system development and acquisition decisions.*

The members of the Working Group were selected for their recognized expertise in several specialties relevant to the general subject of battlefield incapacitation from the use of nuclear weapons. The following is a list of contributors.

This research was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences, National Research Council.

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In addition, considerable assistance and much support were provided by members of the staffs at the Armed Forces Radiobiology Research Institute, the U.S.A. Armor School at Fort Knox, the U.S. Army Nuclear Agency at Fort Bliss, Aberdeen Proving Grounds, Defense Nuclear Agency Headquarters, and R & D Associates, in each of whose facilities the group met on at least one occasion.

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*Colonel Booth replaced Colonel Weckerling in January 1976.
**Captain Moffett replaced Captain Powell in January 1976.

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1. SUMMARY

The effectiveness of nuclear weapons in tactical warfare is very dependent on the situation surrounding and leading up to their use. A battle in the desert or in the barren north would not have the collateral damage constraints typical of defensive actions in West Germany. Nuclear strikes on rear echelon concentrations are very different in character and consequences than a strike on forward elements of an armored assault. Weapon development, nuclear effects research, and military doctrine should give more attention to this sensitivity to circumstances surrounding nuclear employment.

Current criteria and doctrine concerning military consequences of nuclear radiation are necessarily based on experiments with laboratory animals, plus some correlation with human accident and radiation therapy experience and the Hiroshima/Nagasaki data. The responses so derived are largely characteristic of unstressed individuals in clinical or laboratory environments exposed to radiation only. The pertinent military consequences involve whole units (groups or teams, companies or battalions), in environments rich in other hazards, heavy with both physical and psychological stress, and probably without full medical assistance. Most of these factors, if taken into account, would work to reduce the relevant dosages.

Further research should be sponsored to illuminate the group response, the influence of slight decrements in peak performance, the role of battle stress and fatigue, of multiple injury, response delay, and the scaling to humans from animal data. An effort should be made to develop techniques for simulation of radiation sickness symptoms in military groups.

With the present lack of first-hand experience with nuclear warfare in mind, it may be of great importance to be prepared to collect data very early in a nuclear battle, to analyze that data rapidly, and to communicate any useful lessons promptly to other units in the field. Recognition that the results from such a readiness program would be of value could help to keep tactical nuclear operations from becoming overly doctrinaire and inflexible.

There is ample evidence that nuclear radiation from low yield weapons can be an effective casualty-producing agent against tactical assault forces. The many caveats and qualifications considered in this report should not be construed to detract from the fact that nuclear radiation from kiloton weapons is incapacitating (as well as lethal) at ranges beyond those for serious blast damage, thermal burns, or most other effects. At lower dose levels, even below that for latent lethality, the radiation sickness symptoms, while not totally incapacitating, may seriously interfere with combat duties of exposed troops.

A military unit exposed to at least 3000 rad (free-in-air dose*) will be rendered ineffective in combat. Exposure to around 500 rad will cause militarily significant degradation in unit performance within hours; units which suffer less than about 50 rads are not expected to be significantly affected.

Delayed casualties (due to radiation sickness from doses in the 100's of rad) are often as relevant as immediate incapacitation doses (in the 1000's of rad).

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*To the extent possible, all [illegible] [illegible] in-air. Section [illegible] defines the terms more fully.

Doses too low to have tactical significance (<50 rad) may have serious life-shortening effects of consequence to post-war recovery.

The very large variability in human (or animal) response allows some (5%) to suffer early incapacitation at exposures less than 800 rad and yet another few (5%) may not be immediately incapacitated with exposure greater than 8000 rad. These doses correspond to about a 300 m change in range from a 1 kT burst (~500 m for 8000 rad, ~800 m for 800 rad).

As currently defined, incapacitation is too limited a concept, and in many applications might better be replaced by a more continuous measure of performance degradation with dose.

Some (10%) suffer radiation sickness symptoms (vomiting and diarrhea) at doses as low as 100 rad, which occurs out another 300 m farther from the burst point (a range of ~1100 m) of a 1 kT fission weapon. While such wide variations in relevant dosages leave room for some ambiguity and judgment in setting criteria (dependent on the many mitigating factors), the very rapid fall-off with range of nuclear radiation intensity makes the consequences of different choices of critical dose less impressive.

Furthermore, one must be aware of the consequences of "safe-siding" criteria. While the ground range between sure kill (or incapacitation) and sure safe areas is not large in an absolute sense for radiation, it, nevertheless, can make a substantial difference when the object is to stop an enemy attack versus insuring the ability of friendly troops to continue to fight.

2. BACKGROUND

[illegible] makes planning for their use much more uncertain and more subject to contention than are the existing doctrines and criteria for the use of conventional weapons. Actual use of tactical nuclear weapons is likely to result in dramatic changes in nuclear weapon employment criteria as a consequence of lessons learned and new insights gained into the advantages and limitations of nuclear weapons on the battlefield. Although battlefield nuclear experience is lacking, the physical phenomena of nuclear explosions are well known, and their effects on troops and equipment are about as well understood as the effects of conventional weapons.

While it is obvious that a conventional conflict can take place without the use of nuclear weapons, it seems highly improbable that a nuclear conflict will occur without conventional arms also playing a major role. That is, in theater nuclear warfare, conventional and nuclear arms should be considered in a complimentary role.

There is no question that nuclear weapons will bring to the battle vastly greater firepower. However, the consequences of increased dispersal, mobility, and protection for troops faced with nuclear attack should be a part of any evaluation of the effectiveness of tactical nuclear weapons.

More than just greater firepower, or greater destructive forces delivered in shorter time, nuclear weapons promise some rather exotic effects, some permanent, some transient, some immediate and some delayed. The intense nuclear and thermal radiations, the extent and duration of blast and the far-reaching ejecta and fallout hazards are all new to the battlefield. Greater

of expected individual casualty probability than would be expected from conventional weapons attacks.

Considerable attention was given to the total battlefield environment created by nuclear weapons. Most of the pertinent effects in addition to the relevant nuclear radiation doses were reviewed; thermal radiation which causes burns, fires and flash blindness; blast which can damage or destroy vehicles and weapons and can cause injuries and deaths among troops; transient electromagnetic pulses; massive lethal or damaging ejecta from ground bursts; fallout or rainout from single or multiple low yield, low altitude bursts, heavy clouds of dust and smoke--all can combine to present an environment most hostile and unfamiliar to even experienced combat soldiers. Section 5 deals more fully with the totality of nuclear effects.

The response of animals and man to varying doses of radiation under varying degrees of physical stress was considered at some length. Previous analyses of such data were examined, and gaps in both data and analyses were noted. Throughout the study effort, the desirability of additional research was apparent, and the Group has identified some of the more striking needs for further work (Section 9).

To related dosage criteria to military needs requires some appreciation of the complexion of the battle at hand. The war may be one which begins conventionally, but reaches a stage when NATO defense resorts to nuclear weapons in stopping or blunting a Warsaw Pact armored attack; or the war may be one where, after a conventional phase, the Warsaw Pact forces first use nuclear weapons; or it might be a war which starts with massive Warsaw Pact first use.

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Each of these modes of initial use (and others not described) are possible consequences of different scenarios, different weapon deployments, different strategies and different tactics. It follows that the appropriate incapacitation criteria in each case might also differ considerably.

Regarding these scenarios, the Soviet declaratory doctrine for TNW appears to place a high probability on a surprise first-use at the very beginning of a conflict. Recent U.S. official statements give considerable credance to the possibility of Warsaw Pact preemptive first use sometime in the progress of a conventional war.

There is also a growing interest in minimizing NATO-produced collateral damage. Collateral damage constraints relate directly to the problems of targeting, weapon delivery, target response, and dosage criteria. In simple form, the argument is: The larger the required dosage (to gain a given military effect) and the less accurately the target position is known, the larger the required weapon yield; and, in general, the larger the yield, the more the amount of collateral damage. This, in turn, poses the dilemma of trying to balance a high level of confidence in a required military effect with a low amount of collateral damage. In line with the uncertainties associated with imaginary tactical nuclear conflicts, the dimensions of the collateral damage problems are at least as uncertain. An improvement in our understanding of incapacitating doses can lead to corresponding improvements in our collateral damage control. But a better knowledge of the undesired damage to neighboring people and facilities can also contribute to more effective use of nuclear weapons on the battlefield.

3. COMMENTS ON EXISTING DOSAGE CRITERIA FOR TACTICAL NUCLEAR APPLICATIONS

The Army has adopted (based primarily on AFRRI data) a number of dosage levels intended to be used as casualty or effectiveness criteria for military situations. These criteria, now in use by the Army (and accepted by the JCS) are a straightforward and reasonable extrapolation of the results of individual animal experiments.

For these criteria, incapacitation was defined as that point at which the individual (monkey) failed to perform a given task half the time or performed the task at half the established pre-irradiation level. Such a definition ignores any lesser degradation in performance, and pre-supposes that relevant military operations can be continued successfully at performance levels well below normal (but above the 50% or "incapacitation" level). Many critical combat roles do not appear compatible with such a definition of incapacitation, nor do they appear to be any better characterized by the AFRRI definition which indicates incapacitation when task failure has persisted for longer than one minute.

Such strict measures of disfunction seem insufficiently flexible, failing to account for the combat consequences of slight degradations in individual performance. A more generally useful definition of performance decrement appears in the "latent lethality" criterion which is defined at a much lower dose level than "incapacitation." It allows for "functional impairment," and so represents lesser performance degradations than characterized by incapacitation.

In addition, these incapacitation levels refer to unstressed individual animals (extrapolated to man), but not to interdependent teams, crews, or military units under both physical

and psychological stress. These are important limitations, as discussed subsequently. With these limitations in mind, these recently accepted criteria are as follows:

(1) Immediate Permanent Incapacitation (IP).

(a) 19,000* to 17,000 rad band (translated to a radius of damage (R_D) compatible with 18,000 rad). Personnel become incapacitated within five minutes of exposure, and for any task remain incapacitated until death. Death occurs within one day.**+

(b) 9,000 rad to 7,000 rad band (translated to an R_D corresponding to 8,000 rad). Personnel become incapacitated within five minutes of exposure and for physically-demanding tasks remain incapacitated until death. Death occurs in one to two days.**

(2) Immediate Transient Incapacitation (IT).

3,500 rad to 2,500 rad band (translated to an R_D corresponding to 3,000 rad). Personnel become

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*All doses in this report have been converted (approximately) to free-in-air tissue doses, as opposed to mid-line, mid-head, or other tissue doses in a biological specimen.

**The Working Group has been advised that without medical attention, death can be expected in less than six hours.

+The Army does not provide tabulation of the highest level (18,000 rad) in its nuclear weapons employment manuals (FM-101-31-1,-2), as it is anticipated that it would have little real applicability.

incapacitated within 5 minutes of exposure and remain so for 30 to 45 minutes independent of the physical demands of the task. Personnel then recover but are functionally impaired until death. Death occurs in four to six days.

(3) Latent Lethality (LL).

800 rad to 500 rad band (translated to an R_D for 650 rad). Personnel become functionally impaired within 2 hours of exposure. More than half of this group will die; those personnel that die will do so in several weeks, in addition to which, most of those exposed will suffer from some of the effects of radiation sickness, such as vomiting, diarrhea and fatigue.

Appendix E of this report contains a more complete development of these criteria.

As recognized by all those familiar with the problem of predicting human response to massive doses of radiation, useful human data are hard to come by, and extrapolations from animals to man are not well supported. In addition, the animal experiments themselves are far from complete and have not yet led to an examination of all the recognized parameters of importance.

Criteria can be developed either for specific task incapacitation or for degradation of general combat performance. Even lower levels of radiation than accurately specified for immediate transient incapacitation may be appropriate if the combat tasks involve very rapid response times or very heavy physical activity. If time to the onset of incapacitation is relaxed

moderately, i.e., not restricted to incapacitation within five minutes of exposure, and if instead a general level of combat performance over several hours is used as a target model, then that radiation level which would result in significant degradation of combat performance (combat ineffectiveness) would be significantly lower than those for immediate incapacitation. Such criteria, however, could not be based upon a specific radiation effect (behavioral incapacitation), but rather, would be more properly based upon a spectrum of effects as they occur post irradiation. (The current latent lethality criterion is an example.)

A more detailed analysis of post-irradiation performance could be divided into overlapping phases.

(1) Immediate response phase--now termed transient incapacitation. This phase has not been well-described in man in accident cases although it has been extensively studied in laboratory animals. The time of onset in man is only one of the fundamental unknowns. It requires a better understanding of the underlying mechanisms (see Appendix C).

(2) Nausea and vomiting phase. Within a short time after exposure, nausea and vomiting followed by diarrhea will occur. This should be disabling in many combat situations but has not been analyzed against combat attacks in armored operations. Again, this phase must be analyzed and, in particular, compared against the first phase for relative operational impact against general combat [illegible] group (see Appendix F).

These criteria are for individuals, and it is whole military units which are most relevant to the outcome of a battle. These criteria are based on unstressed animal experiments, and multiple effects on weary, worried, injured soldiers may cause them to behave quite differently. The animal and few human experiences are usually with clinical or laboratory [illegible] likely, for instance, that [illegible] to 8000 rad would live for more than six hours without hospital-like medical attention, but men with medical care and restful conditions can survive as long as one or two days. (One or two days is specified in the present criteria.)

Whether or not additional experimentation will lead to a different radiation criteria in the future, the current paucity of relevant human data makes particularly difficult a thorough evaluation of the physiological and psychological impacts of radiation dosages on combat troops. Subsequent sections of this report deal with the many dose-response questions which the Working Group felt were relevant to the confirmation of useful combat criteria.

4. HUMAN RESPONSE TO NUCLEAR RADIATION

ESTIMATES OF DOSES REQUIRED FOR VARIOUS RESPONSES

The nuclear radiation doses expected to cause death (lethal dose) in 10%, 50% or 90% of exposed healthy men are denoted as LD_{10}, LD_{50}, and LD_{90}, respectively. Similarly, the dose expected to cause a particular symptom (symptom dose) such as in 10%, 50% or 90% of those exposed is defined as SD_{10}, SD_{50}, or SD_{90}, respectively.*

Some approximate lethal and symptom doses are listed in Table 4.1. The data base from which these values were drawn, and the spread or confidence limits for each quoted value are presented and discussed in the appropriate Armed Forces Radiobiology Research Institute and Army Nuclear Agency documents summarized in Appendices C, D, and E to this report. Average human body midline doses (in rads) fall about 65% below these free-in-air dose values so that, for instance, the SD_{50} free-in-air value corresponding to vomiting (listed as 330 rad in Table 4.1) would correspond to about 215 rads midline dose in man. There may be other symptomatic responses of interest for which little or no information is available, e.g., the effect of radiation on memory learning, the relation between dosage and response time.

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*The radiation environment to which a man may be exposed can be measured in roentgens, which is a unit corresponding to approximately 87 ergs of gamma ray energy absorbed in one gram of air. A similar alternative unit is the rad (radiation absorbed dose) defined as 100 ergs/gm of radiation absorbed in tissue. Since neutrons have different physiological effectiveness for different organs and symptoms, a Relative Biological Effectiveness (RBE) factor is often assigned to the neutron part of a dose--ranging from an effectiveness less than a corresponding rad dose of gamma rays (e.g., RBE ≈ 0.3) to one of much higher efficiency (e.g., RBE ≈ 10), dependent on the organ exposed or syndrome expected.

Table 4-1. Free-In-Air Doses (in rad) Corresponding to Various Responses for 10%, 50% and 90% of a Normal Healthy Adult Population[a]
(Multiply by 0.65 for Mid-Head Tissue Values)

RESPONSE	10%	50%	90%
ANOREXIA (LOSS OF APPETITE)	(1-90)	180	370
NAUSEA	40	270	490
FATIGABILITY	(15-100)	270	540
VOMITING	70	330	580
DIARRHEA	130	370	600
ULTIMATE DEATH (NO MEDICAL HELP)	330	440	540
FUNCTIONAL IMPAIRMENT WITHIN TWO HOURS	-	(500-800)[b]	-
IMMEDIATE TRANSIENT INCAPACITATION	-	(2500-3500)[b]	-
IMMEDIATE INCAPACITATION - DEMANDING TASKS (PERMANENT)	-	(7000-9000)[b]	-
IMMEDIATE INCAPACITATION - PERMANENT (ANY TASK)	-	(17000-19000)[b]	-

[a]DERIVED FROM DATA FURNISHED BY ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE.

[b]CURRENT ARMY CRITERIA.

NOTE: INSUFFICIENT DATA IS AVAILABLE TO ESTIMATE DOSES WHICH MIGHT CAUSE SIGNIFICANT DELAYS IN RESPONSE TO STIMULI, IMPAIRED VISION, SLOWNESS IN REACHING DECISIONS, AND OTHER SLIGHT OR MODEST DECREMENTS IN MAXIMUM PERFORMANCE.

THESE DOSES DO NOT INCLUDE THE INFLUENCE OF CONCURRENT INJURIES, THE PRESENCE OF ADDED STRESS (BOTH PHYSICAL AND PSYCHOLOGICAL), AND THE LIKELY PRIVATIONS OF THE BATTLEFIELD (POOR SANITATION, LACK OF REST, EXPOSURE TO EXTREMES OF HEAT OR COLD, ETC.).

RELEVANT FACTORS

There are many relevant radiobiological parameters which make a complete and accurate description of human response to nuclear radiation difficult. All of the following factors are recognized as of interest or significance in predicting battlefield responses to radiation:

- Dose level.
- Body dose locality: mid-head; mid-body, free-in-air, bone marrow, etc.
- Type of response; death, incapacitation, sick and needing help, incapacitated or degraded performance.
- Portion of body exposed (non-uniform or not whole-body dosage).
- Size, sex, physical condition, and orientation of body during exposure.
- Syndrome; cardio-vascular, gastrointestinal, hemotopoietic.
- Relative Biological Effectiveness (RBE): mixed neutrons and gamma ray doses.
- Contribution of (n,γ) reactions to internal human dose.
- Weapon or source energy and particle type; n/γ ratios.
- Concurrent activity--stress, exertion, lack of rest.
- Motivation subsequent to exposure--discipline, training, instruction, leadership.
- Emotional state--fear, anger, resignation, apathy.
- Multiple exposures, near-simultaneous and time-delayed doses.
- Synergistic effects of other injuries--burns, abrasions, contusions, fractures--before or after dose.
- Individual variances in response.

- Medical treatment.
- Performance versus time--degree and duration of recovery.
- Clinical responses--anorexia, nausea, fatigue, vomiting, diarrhea, disorientation, reduced visual acuity, irrationality, unconsciousness, death.
- Lack of data (animal or man) relevant to combat performance degradation.
- Uncertainty in extrapolation from animal to man.
- Limited understanding of the relation between unit performance and individual response.

Each weapon application can depend differently on these factors. It's one thing for eyeball-to-eyeball use in stopping an immediate attack, another for use against echelons in reserve, and yet quite another in attacking units in rear-area support roles in logistics or non-combat functions.

SOURCES OF RESPONSE DATA

All the human data come from accidents, wartime exposures, and radiation therapy for cancer patients.

Animal experiments can be fairly rigorously controlled. With adequate resources, many exposures can be studied and sufficient repeatability of data obtained to add confidence to dose-response numbers. However, as described below and in Appendix C, there are residual uncertainties especially for dosage levels far from the median and for particular effects. Recommended research is considered in greater detail in Section 9.

Extrapolation of animal data to predict responses in man is aided by comparison with available human data from the wartime experience at Hiroshima and Nagasaki, from a few nuclear accidents, and from radiation therapy experience. Except in the case of therapeutic dosages, the accuracy in estimating exposures is quite poor, and response is often not well documented. In the radiation therapy cases, the presence of serious disease (most often terminal in nature) complicates dose-response interpretation. The extrapolations from animals to man involves estimating the effects due to differing body size, the differences in physiological response, and the largely unknown role of psychological factors. The correlation of animal response to that of humans is discussed further in Appendix D to this report.

A major source of uncertainty in predicting battlefield consequences from nuclear warfare lies in the differences between unit response and individual response. The military unit represents a system whose workings are not the simple sum of the efforts of all the soldiers in the unit. If half the men in a tank company are incapacitated, it is wrong to assume that the company can operate at half efficiency. The tendency of nuclear effects to be area effects and to apply fairly uniformly over many elements or individuals within a military unit can only exacerbate the problem of deriving group response from individual response. Any symptom, if present at all, may be fairly prevalent and pervasive and affect each crew within a company or battalion. If one or more members of every tank crew in a company is sick, how much less effective will the company be in battle? Some aspects of this organic unit effectiveness question are discussed in Appendices F and G.

DEGRADED PERFORMANCE IN BATTLE

Combat success for tank units correlates well with speed and accuracy in gun-firing. The accuracy with which the gun is aimed, the speed with which it is reloaded, re-aimed and a second round is fired, etc., are the factors that help to determine survival and help to achieve military objectives. Even slight degradations in decision-making or ability to focus or time to take action may tip the balance under fire. Such slight decrements in performance have not been adequately studied in animal irradiation experiments, and have not been simulated with humans.

On the nuclear battlefield, there may be many troops which have been exposed to nuclear radiation, but are not casualties to blast and thermal effects. Tank crews or troops in armored vehicles are likely examples. Such units may remain operational, but suffer from transient radiation-induced incapacitation or degradation in performance. At doses less than are thought necessary to completely incapacitate a crew, the responses may be sufficiently degraded to have pronounced influences on subsequent action. Questions arise as to (1) the time of onset of degraded performance, (2) the duration of the degradation, (3) the degree of recovery and the degree of initial degradation, (4) the time of recovery and the time before remission or ultimate death, (5) the nature of the degradation. How important is it if crew members are slow to respond to stimuli, are impaired by reduced visual acuity, become confused or disoriented easily? How much slower and ineffective can actions be expected to be as a function of radiation exposure, and how much worse would these performance decrements become when combined with battle stress and fatigue? These questions are not well understood or not addressed at all by the past or

current animal experiments or accidental human exposure documentation. These questions are examined in some greater detail in Appendices F and G.

EARLY INCAPACITATION

The doses needed to insure that a soldier can no longer perform his combat tasks are of great interest. Rhesus monkey data has led to the curves of Figure 4.1, which relate the fraction of men incapacitated to the dose they were exposed to. The following observations are based on these curves:

(1) At least 10% will be permanently incapacitated by 2000 rad, 20% at about 4000 rad, but to permanently incapacitate much more than 30% requires a much higher dose.

(2) For early incapacitation, transient and permanent combined, the fraction incapacitated rises steeply from zero to around 75% between 1000 and 3000 rad.

(3) For a small fraction (10%), doses as high as 8000 rad will not cause early incapacitation.

From the above, it can be inferred that doses in the range of a few thousand rads (3000 to 4000 rads) cause such pervasive combat performance degradation within a military unit that effective continued operation is doubtful.

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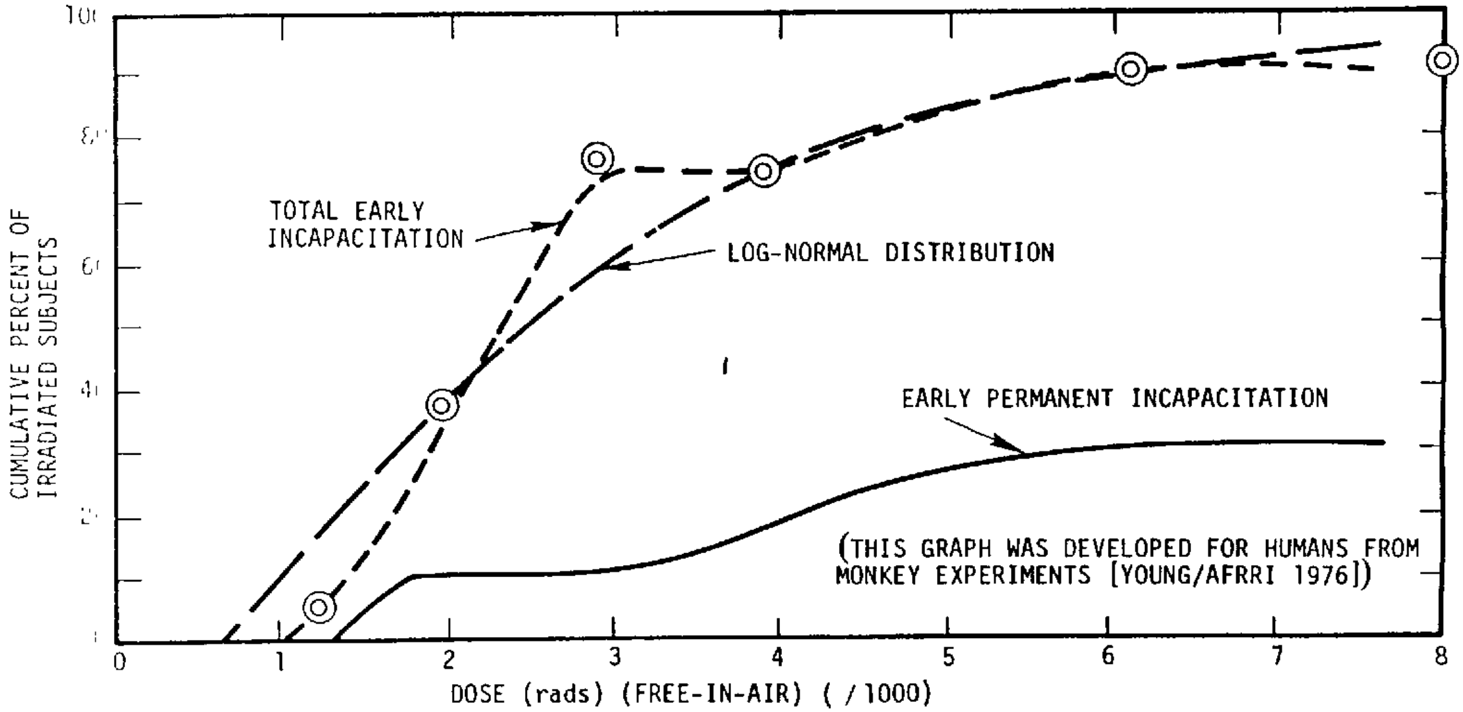

Figure 4.1. Early Incapacitation

NOTE THE TOTAL INCAPACITATION DATA INCLUDES BOTH TRANSIENT AND PERMANENT INCAPACITION PERCENTAGES. THE PERCENT OF TRANSIENT INCAPACITATION IS THE DIFFERENCE BETWEEN THE UPPER CURVE AND THE LOWER EARLY PERMANENT INCAPACITATION) CURVE

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5. NUCLEAR EFFECTS ON THE BATTLEFIELD

Nuclear radiation effects are the principal concern in this report. The use of low yield nuclear weapons makes radiation the dominant effect against men in assault units. The basic requirement for low yield weapons stems from the necessity to limit collateral damage done to friendly troops or local civilians. Even at low yields, however, the blast, thermal, EMP, ground shock, ejecta impacts, and fallout can be militarily significant. Any nuclear burst generates intense heat, which can start fires, cause burns and blindness, and generate a great deal of smoke--even from non-combustible items. The nuclear blast wave can spread rubble from destroyed structures, cause extensive tree blow-down and damage combat vehicles. It can throw many objects at lethal speeds, and can kill or injure men in many ways. The destruction and disruption that a nuclear burst can cause on a battlefield needs to be accounted for in evaluating the effectiveness of such weapons.

It is sometimes as important to damage or destroy the machines of war as to incapacitate enemy troops. Nuclear radiation has little effect on most equipment, and reliable destruction comes from the blast and thermal effects. For destroying an enemy while avoiding collateral damage to friendly troops and local population centers, all of the relevant nuclear explosion effects should be evaluated; blast, thermal, EMP, fallout, etc. In some instances, these associated effects may govern the terms of nuclear weapon employment; they can determine the collateral damage, the effects on friendly troops, and the extent of material damage to an enemy force.

[illegible]

in air, so that at distances of interest for limiting the risk

to civilians, other effects can become relatively more important. For a town which has been evacuated or whose population is well-sheltered, physical destruction of buildings and equipment becomes the principal constraints; fire, blast, ground shock, ejecta impacts, and electromagnetic transients--all of which can cause unwanted damage.

The extent of some of these other factors, particularly those relevant to troops in the battle zone, are illustrated in Figure 5.1 showing their expected ranges for a 1 kT (fission) weapon and suggesting the areas covered by those effects levels. The ragged limits are meant to span the range variability for the onset or threshold of the particular effect named. For example, the threshold for first degree burns is considered to be between 2 and 3 cal/cm^2 exposure on days with visibility from 2 to 100 km and from either a surface burst or a low air burst. At 2 cal/cm^2 and 100 km visibility from an air burst 1 kT, the range is about 1100 m, but at 3 cal/cm^2 with 2 km visibility and a surface burst, the range is only about 600 m.

The point of Figure 5.1 (and of this section) is to bring into view the many hazards that are presented by a nuclear explosion. In assessments of battlefield effectiveness of nuclear weapons, it is wise to consider the devastation and physical disruption in addition to the large doses of nuclear radiation, otherwise estimates of the impact of such weapons can be very wrong.

As an example, consider all that accompanies the dose of 3000 rad which occurs at about 600 m from a 1 kT (fission) weapon. Most of the troops in the open at this range will suffer at least second degree burns on exposed skin ($\sim$7 cal/cm^2), and will be subjected to smoke from paint and vegetation and

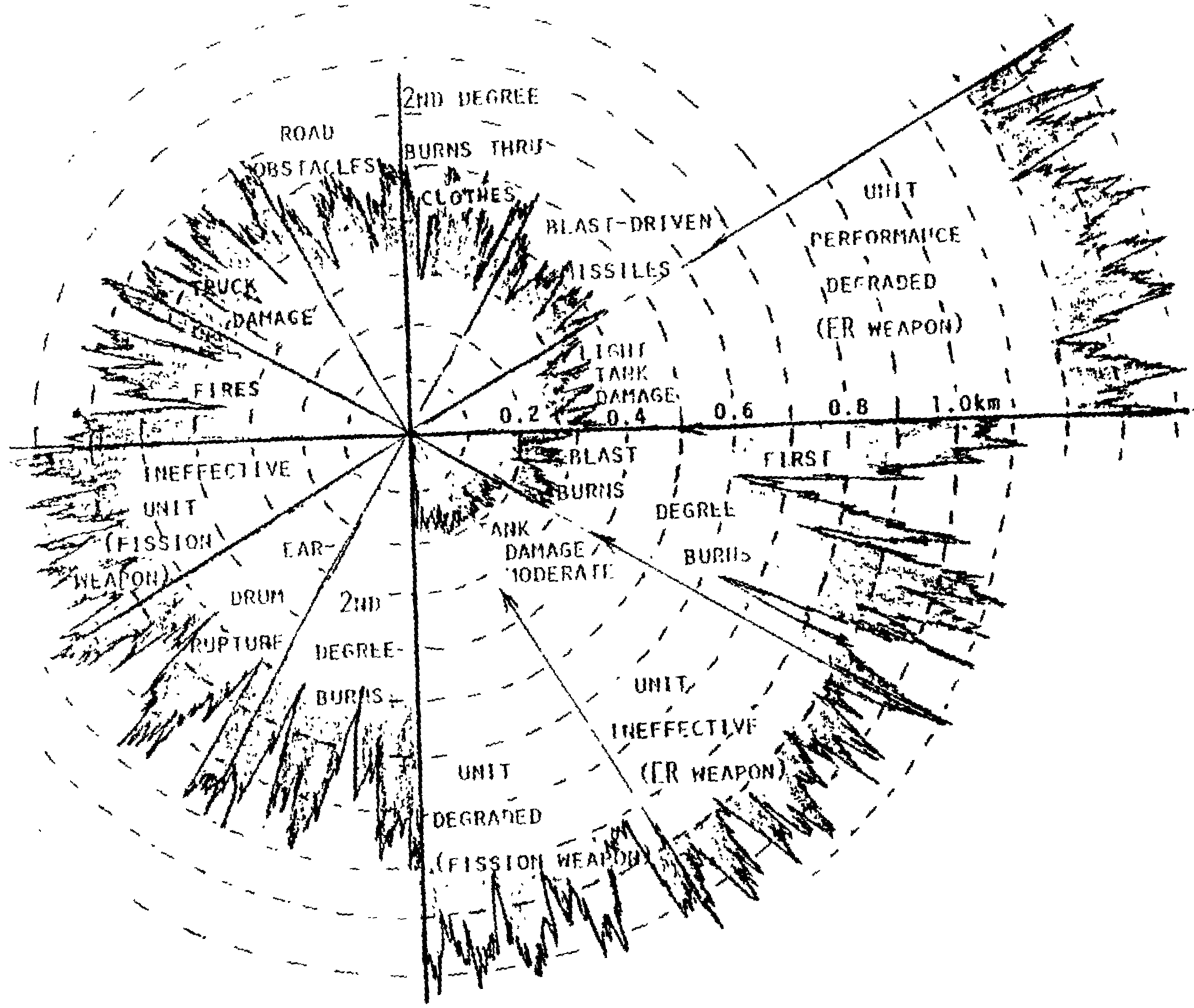

Figure 5.1. Areas Covered by Effects from 1 kT (Fission or ER) WEAPON Low Air Burst

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flame and fires from combustibles. They will have been subjected to eardrum rupturing blast pressures, and some may have suffered some lung damage from blast reflections. Local fallout can become intense (>100 r/hr) over the entire area. The air is likely to be full of blast-generated debris and dust. Nearly all troops will be experiencing some radiation sickness symptoms: vomiting, diarrhea and fatigability. Visibility will be bad, and their vision impaired by dazzle or flash blindness from the burst. Some will suffer eye burns from having caught the fireball in the field of view or even turned instinctively toward it at the moment of burst. Their hearing and orientation may be impaired, telephone and radio communications may be disrupted both by blast effects and EMP.

Troops in armored vehicles are shielded from nuclear radiation to some extent (an effective shielding factor of about 2 in tanks), and may be well protected from thermal radiation. Armored vehicles provide considerable blast protection as well. Heavy vehicles such as tanks do not respond rapidly to the air blast from kiloton weapons and so may lead to fewer injuries from buffeting, sliding, rolling, overturning than in lighter armored vehicles and trucks. However, few vehicles can resist the drag forces above about 15 psi peak overpressure, where the horizontal forces exceed the vehicle weight and can slide, overturn or tumble it.

At this level (600 m from 1 kT) the peak drag pressure of 0.4 psi can lead to forces greater than 5 tons on a vehicle, not enough to roll a tank, but enough to cause injuries inside. Lighter vehicles can be slid, rocked or rolled and more extensively damaged, and occupants injured more seriously. Their further progress may be impeded by downed trees and debris from destroyed structures. If the burst is a surface burst, there may be a rain of rocks and dirt clods (mud balls) of lethal proportions.

It is important to recognize that the mixture of effects can differ considerably with yield or type of weapon. As in Figure 5.1, 3000 rad from a 1 kT fission weapon occurs at around 600 m, but from a 1 kT ER weapon, 3000 rad reaches out to nearly 1000 m, where blast peak overpressure is half that at 600 m, and the thermal little more than a third.

Other factors which affect the combination of weapons effects that bear on soldiers or civilians near a nuclear burst are the target hardness, the amount of shielding afforded, the weather, the time of day, the amount of warning, the proximity of collateral anti-targets, and the nature of the ground cover or surrounding trees or buildings.

An enhanced radiation weapon having a relatively low blast yield could be of value in attacking exposed or relatively unprotected troops near or in an evacuated town without destroying the town, but the same weapon could probably not be as useful against well dug-in soldiers. If troops not on the move have good shelter (earth-covered foxholes), such a weapon would be less effective than one which at the same time can cause blast and thermal damage to the machines and shelters. Situations can still occur where the blast and thermal effects are of importance.

Appendix A gives a fuller description of the effects at various levels of exposure, for yields from 100 tons to 10 kilotons and for doses from 30 rad to 300,000 rad, including those from enhanced radiation warheads.

6. NUCLEAR EMPLOYMENT CONSTRAINTS

One important reason for a preoccupation with low yields in tactical warfare planning is that small yields help to localize weapon effects, limiting the damage areas and so minimizing the impact on friendly troops or on the local civilian population.

As the necessity arises to cover larger areas with larger yields because the region may contain important military targets, the undesired damage to adjacent towns and peoples will increase. To make nuclear weapons more effective against military targets with the least increase in collateral damage to anti-targets, further understanding of the relevant nuclear effects would be helpful. The effects levels pertinent to disrupting military operations are not the same levels relevant to limiting risks for friendly troops and nearby civilians. More information about structures at risk, about available civilian shelter, the practicality or likelihood of evacuation, etc. is needed to deal realistically with the important collateral damage questions.

The relevance of collateral damage to the actual targeting of weapons, once a conflict is in progress is a moot question, but the planning and doctrine which goes beforehand can be, and already has been, influenced by collateral damage considerations. Questions as to the extent to which synergisms exist between non-lethal levels of radiation, heat, and blast exposure need further answers in this regime also.

It is important to know how much more susceptible to nuclear effects is a mixed population with some already sick, with the very old and very young and with a normal or larger than normal component of females.

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The expected resistance of newly constructed houses and buildings relative to that of older construction is of concern--particularly if the new construction proves to be markedly weaker and to offer less protection. The value of evacuation and sheltering as lifesaving measures is generally understood, but needs explicit integration into some of the current tactical warfare models.

While the importance of collateral damage constraints to tactical nuclear operations is commonly recognized, the Working Group was not directed to address this broad issue in depth, and has reserved detailed comment for other Defense Nuclear Agency Working Groups convened to grapple with this particular problem. However, some further observations about collateral effects relevant to the subject of nuclear weapon effectiveness on the battlefield are contained in Appendix B.

7. OPERATIONAL CONSIDERATIONS

This study has necessarily involved considerable examination of tactical operations relevant to the use of nuclear warheads. Some main points are identified in this section, but several appendices to the re[illegible]

In a nuclear engagement, the role of shelters which have been identified or constructed to provide nuclear protection could become very important, but for an armored unit on attack, the available shelter is minimal.

Enhanced radiation weapons have such important effects differences that the operational consequences need separate study. Because the radiation dose falls off most rapidly with distance, if blast and thermal effects are suppressed (reduced), then the distance between targeted military units and friendly troops or civilians can be safely reduced without sacrifice of military effectiveness. Similar distinctions can be made for suppressed radiation weapons, and further separate study may be appropriate for such special weapons, also.

The complex interaction between the performance or degree of incapacitation of an individual and the survival or ineffectiveness of a combat unit plays an important role in the setting of meaningful criteria.

Large differences exist in the doses required to have significant impact on military units, depending on the immediacy and duration of their combat roles--a dose well below 1000 rad may make a reserve unit unavailable for subsequent combat assignment while prompt defeat of a tank company in assault may require much larger doses.

The influence of other battlefield degradations, including the effects of conventional weapons as well as the blast and thermal effects from a nuclear attack can work to make the lower doses effective in producing casualties. This can come about from synergistic effects between multiple injuries and radiation exposure. It can also be induced by the added physical demands of repairing and operating damaged vehicles, equipment and weapons.

The area effect of nuclear weapons, and the infliction of many casualties simultaneously could have significantly more effect on unit performance in comparison to similar casualty levels from conventional weapons.

The particular battle circumstances, e.g., the season, location, warning, any prior action, the military objectives and battle stage being dealt with, can have great influence on the effectiveness of nuclear weapons and on the reasonableness of selected criteria or doctrine.

It is clear that the many facets of the tactical use of nuclear weapons make for a complex problem in insuring effective applications. At the same time, it is obvious that guidelines for employment must be simple and direct for use in the field, precluding extensive field analysis or data gathering--prior to weapon delivery.

Since tactical operations with nuclear weapons have never occurred, it is particularly important that field units be prepared and equipped to absorb, record, analyze and use to good advantage all lessons learned from their first nuclear experiences. Rapid communication of these lessons, and quick changes as a consequence in [illegible] of utmost importance.

8. FINDINGS

- Nuclear weapons are area weapons for most battlefield targets.
- Tactical targets are usually area targets.
- Tactical nuclear warfare is likely to superimpose nuclear effects on conventional warfare effects, so that TNW planning should combine both conventional and nuclear effects.
- At low yields and without very good below-ground shelter, the threat to human life is dominated by nuclear radiation.
- There is a paucity of useful human radiation exposure data.
- Criteria for TNW effectiveness are dependent on the particular situation; for a war of extended duration, delayed casualties may be as important as immediate incapacitation.
- Delayed casualties can have an influence on a battle, but will more seriously affect a war or a post-war recovery period.
- Uncertainties and variations in weapon output and air transport are less than a factor of two--corresponding to range variations of less than ± 100 m.
- Below exposures of 50 rad, few humans show prompt symptoms.
- Above exposures of 100 rad, humans begin to show some immediate reaction.
- A dose of roughly 250 rad will cause fatigability that may persist for weeks, vomiting, diarrhea, nausea and other radiation sickness symptoms that may last for days for many individuals (less than half); even death for some (5%).
- At about 450 rad, 50% of those exposed die within 60 days (without extensive medical treatment).

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mid-line or mid-head doses by a factor of 1.5 to 1.8 for monkeys or man.

- At 1000 rad or more, humans experience serious dysfunction within very short periods after exposure.

- At 1500 rad exposure, some humans are expected to become totally incapacitated early. (About 10% of those exposed to 2000 rad are expected to suffer early <u>permanent</u> incapacitation.)

- Above 3000 rad, most soldiers (about 75%) exposed are expected to become incapacitated (for at least a half hour, after a few minutes).

- About 20% suffer early <u>permanent</u> incapacitation at exposures of 4000 rad.

- The variability in human response insures some significant degradations below 150 rad and some non-incapacitation above 8000 rad.

- Performance of some physically-demanding tasks may be degraded by sublethal doses.

- The relative biological effectiveness for neutrons is different for different responses (e.g., ~0.6 for prompt incapacitation, ~10-20 for cataract formation).

- Because radiation exposure can reduce resistance to infection and shock or trauma, some normally non-lethal injuries may lead to death from sublethal doses.

- Physiological stress or injury <u>before</u> exposure to radiation can decrease the severity of the radiation response.

- No useful human or animal data exist which combines psychological stress with radiation exposure.

- Little useful data exist which define the effect of radiation on maximal performance or learning ability.

- The extrapolation from animal to man is complicated by size differences, unknown response differences (physiological), and probable motivational factors.

- Fatalities are not the only concern in assessing the collateral damage potential of tactical nuclear weapons--injury and property damage can be too extensive to ignore.

- At and above ten kilotons, kill or damage probabilities for [illegible] thermal effects (rather than radiation).

- At about one kiloton, where the ranges for radiation and for blast and thermal collateral hazards are comparable, synergistic effects can contribute to a lowering of the effective lethal dose.

- For yields below a kiloton, or for enhanced radiation weapons around a kiloton, radiation effects can dominate collateral casualties among an unsheltered population.

- Uncertainties in nuclear effects at low levels has led to larger avoidance distances for collateral damage limitation than ultimately may be necessary.

- Uncertainties and variations in lethal dose responses--particularly at the lower dose response levels (LD_{2-10})--can be very large (as great as a factor of ± 2)--corresponding to an additional range variation of ± 100 m. Factors contributing to the uncertainty:

  - Limited data base
  - Unknown RBE
  - Synergistic effects
  - Weaknesses of old and sick persons
  - Wartime degraded sanitation and public health (privation)
  - Limited medical care

- Variations in shielding factors for building basements of a given class can be factors of ± three to five; and variations due to position within a given shelter can be comparable.

- Location and status of the population are more uncertain and subject to more variability than weapons effects and biological factors and such variables should be handled separately, in the context of prior events, warning times and battle circumstances.

- There appears to be no plan to collect data relevant to nuclear weapon effectiveness in actual battlefield use, nor any methods developed for the reduction, analysis, evaluation and application of such information.

- Average tank shielding provides at best only about a factor of two reduction in initial nuclear radiation, and in actual field operating modes, even that factor may not be fully realized.

- [illegible] effort. frequently calling for rapid response, [illegible] decremently degraded by small decrements in peak performance (as induced by radiation exposure).

9. RESEARCH RECOMMENDATIONS

- Establish the factors that determine the response of combat units (tank crews, tank companies, artillery crews and battalions, infantry companies, brigades, divisions, etc.) to relevant nuclear radiation exposures.

- Assess the influence of slight degradations in performance on military unit or team effectiveness.

- Extend or continue studies of the role of stress in the response of humans and animals to nuclear radiation.

- Investigate the influence of fatigue on human or animal response to radiation.

- Study the influence of injury on the dose-response relationship.

- Document the effect of prompt dose on judgmental, cognitive, or discriminative task efficiency--including slight degradations.

- Improve the understanding of response delay after prompt dose in humans; the chronic transient behavior expected, including distracting, degrading, and incapacitating responses.

- Resolve the disparity between external and midline dose-response relationships and the scaling of dose-response relationships with body size, and the effects of partial body shielding.

- Through field exercises and simulated effects, study the roles of training, indoctrination, discipline, and leadership on the mitigation of immediate radiation effects.

- Explore the differences in physiological reactions to significant radiation doses as a function of species, with the objective of better predictions of human response.

- Improve the understanding of the degradation and incapacitation responses of animals and humans as a function of dose level and time after irradiation.

- Develop realistic simulants for radiation sickness symptoms for use in studies of operational group responses.

- Investigate methods for rapid analysis of battle results and data reduction and evaluation, to facilitate timely improvements in tactics and doctrine for subsequent or concurrent engagements.

- Re-evaluate field dosimetry techniques in the light of a need for approximate rather than precise dose data.

10. CONCLUSIONS

Findings and research recommendations of this Working Group are recorded in the previous sections (Sections 8 and 9). The following four conclusions represent the direction of the Group's judgment, in general. Some justification and more detailed evaluations are covered in the previous sections and in the following appendices relevant to kiloton weapons.

- Company or battalion-sized tactical units (at least a few hundred meters in dimension), when exposed to 3000 rad (free-in-air dose), i.e., when encompassed by the 3000 rad contour, will suffer such extensive incapacitation as to be rendered ineffective on the battlefield.

- Tactical units exposed to hundreds of rads (on the order of 500 rads free-in-air dose) will suffer militarily significant degradation within a few hours.

- Military units exposed to less than a few tens of rad (on the order of 50 rad free-in-air) are unlikely to suffer any militarily significant degradation.

- An effort should be made to insure the initial collection of relevant nuclear battle data and the rapid utilization of that data in changing doctrine or improving tactics in the field.

A portion of the Working Group is of the opinion that unit ineffectiveness would occur at a dose at least a factor of two below the 3000 rad value. Another fraction of the Group believes that while a lower value may indeed become appropriate,

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more research findings are necessary before such a reduction could be justified. Still another faction believes that the current information does not indicate any further reduction, and that a more accurate answer may not be possible, based on animal data alone.

In any event, an uncertainty of a factor of two up or down in dose corresponds to a range variation of only ± 100 m. For opposed forces in close contact, where differentiation between sure safe and sure incapacitation is at issue, such uncertainties are nevertheless of enough importance to justify continuing investigation. Results from research cited in the previous section may provide a sound basis for modifying either the Army/JCS criteria or the above-suggested exposure levels.

The emphasis in these conclusions is on the combat unit or group response as distinguished from the response of an individual soldier to radiation or injury. While less is known about team response than about individual response, it is felt that in many critical circumstances the sudden illness of many crew members would cripple the functioning of a combat group, and that far less than total incapacitation for each individual would lead to mission failure on the battlefield. When more than half the men in a combat unit are sick--vomiting and suffering from diarrhea--their ability to function as a crew, team, or combat unit may be seriously degraded or even disappear.

Doses which are usually sublethal in clinical circumstances may cause casualties and deaths on the battlefield, particularly when combined with blast effects, thermal burns, battle injuries, fatigue and stress. These factors and others, such

[illegible]
battlefield [illegible] functioning [illegible] personnel,
can contribute to a reduction in the minimum dose needed to interfere with the military capability of a combat unit.

At relatively low doses, i.e., hundreds of rads, subsequent commitment to battle may be only with the expectation of further degraded performance. Many such exposed men will require medical attention or relief from their battle responsibilities. (The threshold for radiation sickness symptoms occurs below 100 rad.) In fact, significant unit degradation may begin well below 500 rad, dependent somewhat on unit training, indoctrination and morale. The dose level for significant influence on well-prepared combat units remains uncertain to a factor of two. For this factor, the corresponding range variation is again about ± 100 m or ± 10% at 1 kT.

Prompt clinical responses are not detected in individuals exposed to 50 rad or less, nor do any noticeable physiological or health factors usually occur within the next few months following exposure to less than 50 rad, so military units exposed to such a level should not be significantly affected. However, radiation damage to human cells may cause life shortening. Individuals amongst the exposed group may develop cancers and radiation-related maladies that may complicate post-war recovery, the rehabilitation of veterans or civilians, may threaten longevity, and burden health care systems, but should have no real effect on the outcome of a battle, or even a protracted war.

A readiness program to make maximum prompt use of TNW lessons should have at its core an information collection and analysis

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system with proven instrumentation, recording, reduction and interpretation components. Such a system should be in the field for instant activation at the outset in any nuclear use. Advanced decisions should be made as to what observations are vital and what should be done in analyzing the data. Questions of weapon effectiveness versus target types and perhaps of collateral damage versus military objectives achieved should be anticipated. The value of rapid assimilation of lessons learned is potentially very high in the case of first use of an untried weapon system such as tactical nuclear weapons.

Emphasis in this report has been on low-yield nuclear weapons, a class of weapons for which nuclear radiation becomes the dominant effect against armored troops. However, a nuclear explosion creates many other nearly simultaneous hazards. These other hazards and their relation to the radiation levels of interest and the ranges at which each occurs is the subject of this Appendix. The areas covered by doses from 3 to 300,000 rads (free-in-air) from one kT fission and a one kT enhanced radiation (ER) weapon together with the ranges and the levels of other effects are illustrated in Figure A-1 and in Table A-1. Some appreciation for the consequences of these various exposures can be gained from the following description of probable consequences at these ranges and radiation levels.

At the 3 rad level (30 rad from the ER weapon) or beyond, slight immediate effects are expected, and few serious casualties will occur. Some windows will be broken by the blast, some other minor blast damage and some fallout may occur. If the burst is a surface one, then lethal levels of fallout radiation (>120 rad/hr) may extend for many kilometers, covering an area of 1 to 4 km^2 with a total integrated dose of more than 600 rad--extending downwind 3-7 km, depending on the local winds. Serious fallout (~30r/hr at 1 hr or integrated doses of as much as 200 rad) will extend over an area of some 3 to 9 km^2 or 5 to 10 km downwind. Eyeburn for those caught looking in the direction of the burst is still a potential hazard at distances of 10 or 20 km. Otherwise, the effects at the 3 rad (fission weapon) prompt dose range and beyond are sufficiently unimpressive that friendly troops and civilians in the area would not be considered in immediate danger.

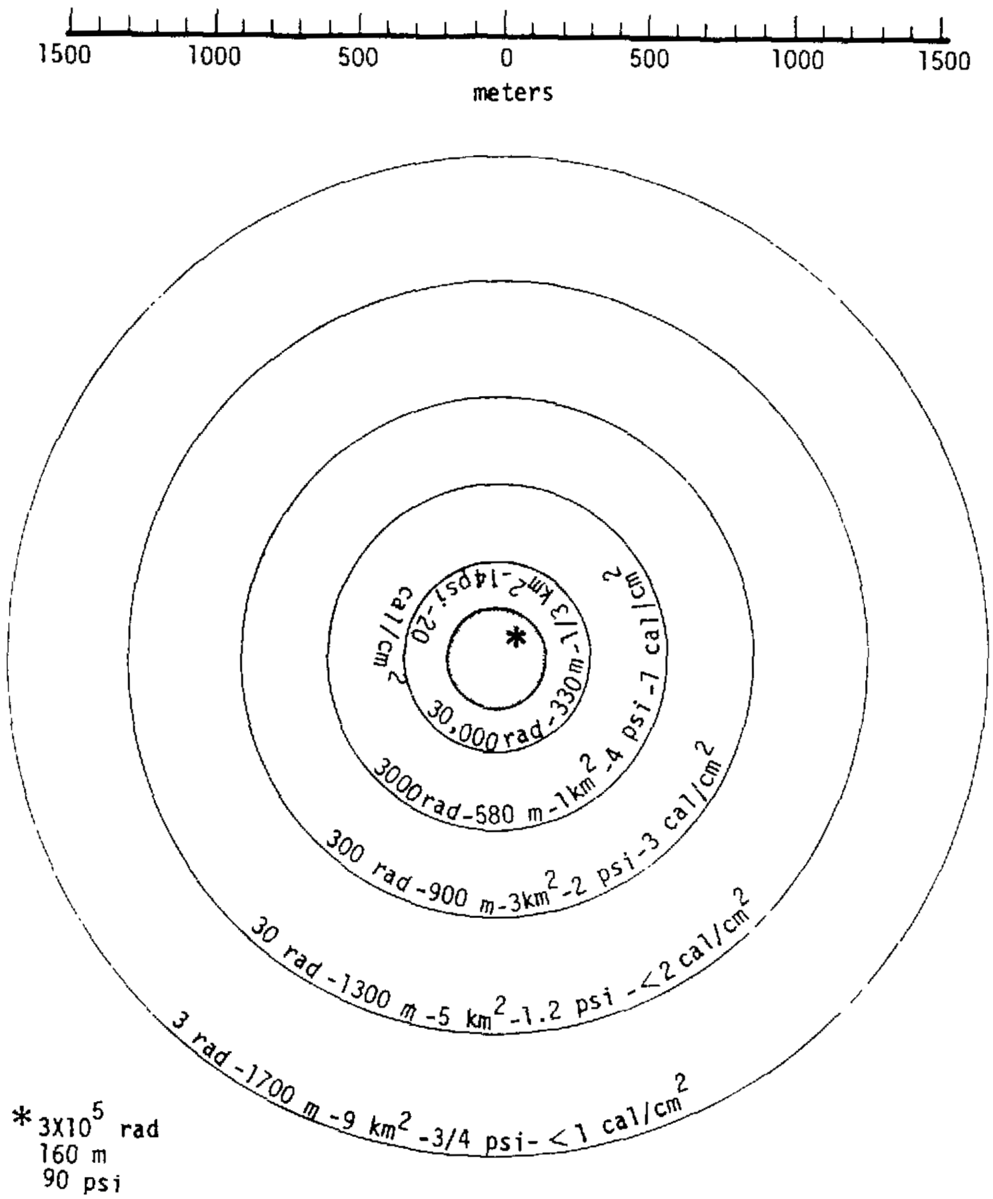

Figure A-1. Areas Covered by 3 to 300,000 rads (Free-in-Air) Doses from 1 kT Fission (100 m HOB)

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Table A-1. Nuclear Environment at Ranges from 1 kT where Doses are 3 - 3×10^6 rad Free-in-Air (in Decades)

DOSE (f-i-a)* 1 kT FISSION	GROUND RANGE (m)		AREA (INSIDE) (km^2)		PEAK OVERPRESSURE (psi)		PEAK DYNAMIC PRESSURE (psi)		PEAK BLAST WIND (m/s)		THERMAL RADIATION (cal/cm^2)		EJECTA 10 kg IMPACTS PER 100 m^2 AREA	DOSE (f-i-a)* 1 kT ER+
RADS	SUR-FACE	100 m HOB	πR^2	ΔA	SUR-FACE	100 m HOB	SUR-FACE	100 m HOB	SUR-FACE	100 m HOB	SUR-FACE	100 m HOB		RADS
3	1700	1700	9	4	0.6	0.8	0.01	0.02	10	13	0.14-.4	0.3-0.9	0.003	30
30	1300	1300	5	3	0.9	1.2	0.02	0.03	15	19	0.3-1	0.8-1.6	0.007	300
300	900	900	3	2	1.6	2	0.06	0.11	25	32	0.8-2	2 - 3	0.02	3000
3000	580	580	1	0.7	3	4	0.3	0.4	50	60	2.4-5	6 - 8	0.08	30000
3×10^4	330	320	0.3	0.25	9	14	2	3	120	160	8 - 14	21 - 24	0.4	3×10^5
3×10^5	160	120	0.05	0.05	40	90	30	100	370	600	40 - 61	99 -105	4	3×10^6

*f-i-a = FREE-IN-AIR DOSE (AS OPPOSED TO TISSUE DOSE).

+ER REFERS TO AN ASSUMED "ENHANCED RADIATION" WEAPON CHARACTERISTIC OF 10 FOLD MORE NUCLEAR RADIATION FOR THE SAME NUCLEAR YIELD, AND THE SAME SPECTRUM AS FOR THE "STANDARD FISSION" WEAPON.

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Between 1.3 and 1.7 km from a 1 kT burst (3 to 30 rad for a fission weapon, or about 30 to 300 rad for an ER weapon), most of the blast, thermal, or other effects do not present immediate threats to life. Fallout from surface bursts can, of course, add to the dose of radiation at these distances, but most of it can be avoided by moving out of the area or by seeking or constructing adequate shelter. Eye burn is a greater hazard at these closer distances, since the image size on the retina grows larger at closer ranges, but still only if the fireball image is caught in the field of view with an open eye. In general, troops exposed at these or greater ranges (beyond 1.3 km) will be able to continue their tasks. For an ER weapon, however, doses from 30 to 300 rad in this region will cause radiation sickness symptoms and death for a few (~10% at the 300 rad level).

Between 30 and 300 rad (at around ranges of 900 to 1300 m for a 1 kT fission low air burst), exposed troops can develop the radiation sickness symptoms, such as vomiting, diarrhea and fatigability. They also may suffer first degree skin burns from the thermal radiation. They may find themselves engulfed in dust and smoke clouds generated by the thermal and blast winds of as much as 32 m/sec. Windows will break, and shards will fly with velocities up to 30 m/sec. Wall and roof panels, sheet metal siding and other materials used in light construction may tear loose and fly about. Roof tile may fall. Troops in this area from 30 to 300 rad (~3 sq km) will know they have been attacked. They will feel heat and blast, and suffer radiation effects. Some may suffer eye burns, and most will be dazzled or temporarily blinded by the flash. But most are likely to survive, and many have a good chance of being able to continue in combat. Only a fraction will become casualties (10% may die); about half of them will be bothered by radiation sickness symptoms.

For this dose range (30 - 300 rad free-in-air), troops in the shelter of tanks, armored personnel carriers, or field fortifications, may be spared radiation sickness. While some men, when subjected to doses between 100 and 200 rads, experience mild nausea, vomiting and diarrhea, they may suffer more serious dysfunction under stressful conditions. In most cases, fatigability persists for weeks. Ten percent of those estimated to have been exposed to doses between 100 and 200 rad at Hiroshima or Nagasaki died following a chronic illness. Death was often attributed to malnutrition or infection. Anemia often persisted until time of death.

At these same ranges (900 - 1300 m) from a 1 kT ER weapon, the doses of 300 to 3000 rad represent a far more serious hazard than presented by the blast or thermal. Here, good radiation shielding (a meter of earth or 60 cm of concrete or stone) could shield troops from these lethal radiation levels, and help protect them from blast and thermal as well.

At closer ranges (600 to 900 m) where the dose from the 1 kT fission low air burst goes from 300 rad to 3000 rad, much more serious consequences await the exposed soldiers. Unless shielded, most soldiers in this range will eventually die from the radiation exposure, and in the interim their immediate radiation sickness symptoms will be more violent and more pervasive. Nearly all will suffer vomiting attacks, diarrhea, and fatigability. Thermal radiation fluences as high as 7 cal/cm^2 will occur, and all exposed skin will suffer second degree burns. Many of the lighter ignitable materials will be charred or in flame. Such things as grass, leaves, clothing, bedrolls, papers, curtains, and upholstery will burn or char. At blast overpressures up to 4 psi, many houses will be heavily damaged and walls toppled. Some trees may be uprooted by the

peak blast winds of up to 60 m/sec. Trucks can be overturned by the blast drag pressures up to 0.4 psi (more than 5 tons of force on a typical truck). Roof tile and loose debris may be picked up and thrown by these blast winds.

Much debris, dust and smoke will fill the air and impair vision. Eyeburns or dazzle and flash blindness may be immediately serious for exposed troops. The blast of several psi at these ranges can throw a man in the open at 3 to 6 m/sec. (The human skull will begin to crush when thrown at a velocity of 5 m/sec against a solid object.) Rubble strewn on roadways and tree blow-down will inhibit mobility in this area. Most exposed troops in this range (600 - 900 m) will die; many will be immediate casualties. Many units will be stopped, some may not recover or be able to regroup and resume an attack.

The area where the expected exposure dose from a 1 kT fission weapon is between 300 and 3000 rad is about 1.5 km^2. For soldiers in tanks and armored personnel carriers, the blast and thermal hazards are not so serious. The tank commander riding with his hatch open would suffer thermal burns and blast effects, and some heat, smoke, and blast will enter the tanks or APCs unless they are buttoned up. For the 1 kT ER weapon at these ranges (600 - 900 m), the higher doses (from 3000 to 30,000 rad) are in the range for immediate incapacitation and certain death.

The region between approximately 330 to 580 m, an area of about 0.7 km^2 is one in which all but the best sheltered troops will be killed by a 1 kT fission warhead. Those that survive the immediate effects will have received more than a lethal dose, and many will die within a few hours, all within a few days. The radiation sickness response will in most cases begin very

soon after exposure, and in many cases will continue without relief for hours or days until death.

In addition to radiation sickness, troops can suffer lung damage from the free air blast of up to 13 psi (often magnified by reflections up to 35 psi or more). Death and injury are likely for troops in the open just from being thrown by the blast at velocities up to 15 m/sec. (Translation velocities of 6 m/sec are estimated to cause 80% fatalities.) Trucks will be violently rolled or lofted in peak winds up to 160 m/sec, and smashed by blast dynamic pressures as high as 4 psi (2800 kg/m^2 or more than 50 tons of force on a broadside tank or truck). Such forces are sufficient to violently move even a tank weighing 50 tons. Under these blast-induced motions, occupants may suffer death or fractures, contusions, lacerations, and experience peak accelerations of more than 10 g inside a tank.

Heavy damage will be suffered by all buildings in this zone (330 - 580 m), and much debris will be translated by the blast at velocities in excess of 100 m/sec. If the blast is a surface burst, crater ejecta will fall in this region, with a fair probability that vehicles will be hit by clumps or rocks weighing more than 5 kg, and men, even in foxholes, will be hit by ejecta clumps of more than a kg. The dust and smoke will be thick, and will persist until fires burn out and surface winds can carry off the lingering smoke and dust. Visibility may remain very low for half an hour or more. Many trees will be uprooted or broken, making passage in forested areas or along tree-lined roads slow or impassible. For a low air burst, the thermal radiation from 1 kT at these ranges (330 m - 580 m) lies between 3 and 24 cal/cm^2, which means severe burns to all exposed skin, burning or charring of exposed clothing, and ignition of most exposed ignitables.

Vehicles may catch fire, and the smoke from all exposed surfaces and charring vegetation will be heavy and dangerous to breath and hard on eyes even inside vehicles or shelters. Troops in tanks and APC's may avoid direct burns, but blast injury is likely. Troops in closed underground shelter with earth cover may avoid injury altoghether, unless the shelter collapses under the blast loads (as high as 10 tons per square meter). An ER weapon can lead to doses from 30,000 to 300,000 rad free-in-air in this range (330 - 580 m), and only very deeply buried shelters (~3 m earth cover) could provide enough shielding for survival.

This decade of doses (30,000 to 300,000 rad) from a standard fission weapon occurs at distances from ground zero (from a 100 m burst height) from 120 to 320 m, covering an area of only 0.3 km^2. In this relatively small region, the blast and thermal effects become lethal for all but the best sheltered troops. The overpressures run from 13 to 90 psi, and the corresponding dynamic pressures can go from 4 to 100 psi. Peak drag forces on a tank (side-on) can go from 50 tons (at 4 psi) to 1400 tons (at 100 psi). The blast winds of up to nearly 600 m/sec make flying debris out of almost everything above ground, and will even scour up the surface dirt and small rocks and carry them along to impact further out, or to contribute to the dust clouds. All trees and most above-ground structures in this zone will be down, and the rubble and tree debris can delay subsequent traversal.

Thermal radiation levels are so high that the surfaces of tank hulls and other metal surfaces will develop some melt and will retain high temperatures. Stored ammunition or fuels may be vaporized and/or ignited. All surfaces will be charred, blistered, melted, vaporized, or ablated. Units within this region will have few survivors and no chance of being sustained in combat as a fighting unit.

Of course, the doses in this region are at least an order of magnitude above the level considered by the Working Group to be sufficient to render ineffective a combat unit, and only very massive shielding of personnel could avoid death for them, from either standard fission weapons or ER warheads. In the innermost region (inside 150 m from ground zero), the fission weapon dose exceeds 300,000 rad, and the other effects are correspondingly overwhelming. The area is relatively small, however, and represents a scorched earth region. Even field fortifications and below-ground shelters are likely not to survive.

The effects levels listed in Table A-1 were generated using the following formulae and assumptions.

Nuclear Radiation (Nominal Fission Weapon)[A-1]:

$$D = D_n + D_g = 10^9[12 \exp(-\rho R/220) + 6.4 f \exp(-\rho R/326)]W/R^2$$

ρ = air density in gm/liter $\approx$ 1.20

R = range in meters

W = yield in kT < 100 kT

f = fission fraction $\approx$ 1

The neutron source factor (12) includes a neutron RBE factor of 0.6 for prompt effects (without it, the factor would be 20), and strictly speaking the dose should be considered a free-in-air REM rather than RAD dose. Omitting this RBE, the quoted doses instead of being 3, 30...300,000 would be 3.2, 34, 370, 4000, 42000, 430000. On the other hand, if the air density were increased, as on a cold sea level day to 1.30 gm/liter, these same free-in-air doses become 1.8, 22, 260, 3100, 37000 and 410,000. For enhanced radiation weapons, the source factor

has been increased ten-fold, making all doses a factor 10 higher at corresponding ranges.

The expected variation in doses due to differences in sources (weapons design differences), variations in atmospherics (air density changes due to altitude and temperature), and other local influences such as shielding, scattering and (n,γ) production in adjacent materials when combined with possible different biological effectiveness values for different response symptoms makes literal interpretation of the dose values quoted in Table A-1 fruitless. However, because of the rapid change of dose with range, only slight variations in range are necessary to compensate for rather large dose variations. A range change of a hundred meters results in about a factor of two dose change for 1 kT.

Overpressures are based on values given in DASA 2506 [A-2].

The peak overpressures for surface bursts are given by

$$\Delta P = 8.93 \times 10^7 \frac{W}{R^3} + 40620 \left(\frac{W}{R^3}\right)^{1/2} + 0215 \text{ psi}$$

R in m

W in kT

For air bursts, interpolated values from Figures 1 and 2 of DASA 2506 were used. These values are subject to local variations in typical terrain, and can be expected to vary by as much as 20% in range, and can be degraded even more by heavily built-up or wooded surroundings.

Peak dynamic pressures were approximated by

$$Q = \frac{\Delta P^2}{41.16 + 0.4\Delta P}$$

with both Q and ΔP in psi [A-1]. This is the Hugoniot or shock value for an ideal gas of $\gamma = 1.4$ and an ambient pressure of 14.7 psi. Precursed shocks can lead to larger peak dynamic pressures (by a factor of two or more), and heavily built-up or wooded areas can lead to much reduced dynamic pressures (as little as a half).

Peak blast wind values were approximated by

$$U = \frac{634\Delta P}{\sqrt{(6\Delta P + 103)14.7}}$$

with U in m/sec and ΔP in psi. This also represents the shock value of peak particle velocity for an ideal gas of $\gamma = 1.4$ in a sea level standard atmosphere ($P_O = 14.7$ psi). Non-ideal shocks such as in precursors or in wooded terrain can lead to winds 50% higher or lower.

The thermal radiation is approximated by

$$H = \frac{2.65W}{R^2} (1 + 1.4\ R/V)\ \exp(-2\ R/V)$$

in which the thermal radiation H is in cal/cm^2, R and V are in km, and W is in kT. This form includes an approximation to atmospheric attenuation in terms of the range R and visibility V due to Gibbons (see Ref. A-3), and is for an air burst. A surface burst produced about half as much thermal radiation.

Visibilities can be less than two kilometers (in fog or rain or smoke or dust) and yet can be greater than 100 km on clear days. The values in Table A-1 show the spread in calories/cm^2

due to these two visibility values, 2 km and 100 km. At the largest ranges considered (less than 2 km), the difference is about a factor of 3. Terrain, cloud cover, ground cover, and burst height can all also contribute to the variability in the thermal exposure.

The ejecta impacts were calculated by assuming a contact burst in wet soil, leading to a crater volume of 1400 m^3 for 1 kT [A-4]. The distribution of ejecta was assumed to follow the form [A-5]

$$d/V^{1/3} = 0.1\ (V^{1/3}/R)^3$$

in which d is the ejecta depth, V the crater volume, and R the distance from the burst. The ejecta was assumed to be of a specific gravity of 2, and half in 10 kg missiles (a gross assumption, but not drastically in error for some high explosive experiments). Thus, the number of 10 kg missiles per square meter is given by

$$N = 100\ d, \text{ when d is in meters.}$$

The number and size of such ejecta impacts are a sensitive function of the cratering efficiency of the burst, and depend very much on the soil type, the weapon coupling to the ground, and the weapon type itself. Large variations may be expected in ejecta distribution due to jets or plumes out of the crater. For bursts above the surface, even at low burst heights, almost no ejecta is expected.

All of these estimates of weapons effects are uncertain. Some indication of the expected variability in these phenomena has been suggested, but the greatest variation and uncertainty lies always with that of target response. A tank is much harder to roll front-on than side-on. One building may stand

at 6 psi while another may collapse at 2 psi. One village may be consumed by fire at 4 cal/cm^2 while the next survives unburned at 12 cal/cm^2. In summer, the dry leaves and grass may fill the air with thick smoke. In winter, the frozen ground or snow may not respond at all.

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APPENDIX B. COLLATERAL DAMAGE CONSTRAINTS

Small population centers (villages, dorfs) a kilometer or two apart with larger towns and cities frequently within ten or so kilometers of each other make very difficult the avoidance or minimization of damage to non-military property and civilians during combat in such an area. Even without an indigenous population in the battle zone, nuclear weapons of small yield have the potential for less damage to friendly troops than high yield weapons and, in many cases, at little cost to military effectiveness.

The ranges for a few relevant effects on people and their possessions are illustrated in Figures B-1, B-2 and B-3 for yields of 10 kT, 1 kT (fission and ER), and 100 tons nuclear. Fallout of serious intensities can cover larger areas than any other significant effect from these weapons, but only for bursts low enough to crater the ground. Of course, some fallout must be expected from air bursts, but the distribution is more widespread and less intense than that from surface bursts. For bursts above the surface, the blast and thermal extend further than for a surface burst, and the prompt radiations are not seriously reduced. The ranges (and areas) in these figures are for a 100 m burst height and for a surface burst.

The ranges in these illustrations are free-field values, and as such are most relevant to people in the open and to unprotected structures. As people usually seek shelter or evacuation with the approach of battle, only those unfortunates caught in transit or unawares at the time of attack will be exposed to the thermal and the full force of blast and unshielded nuclear radiation.

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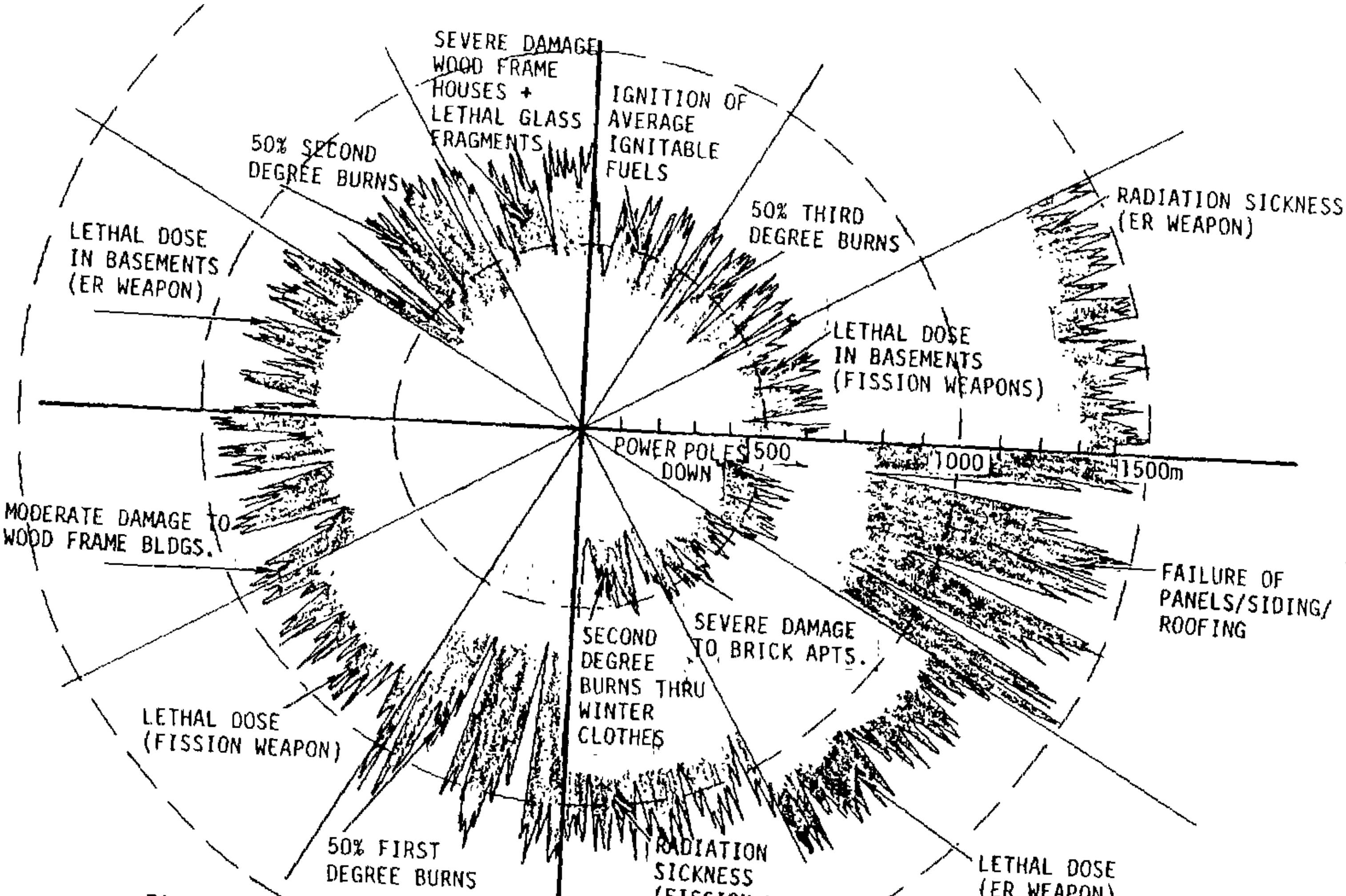

Figure B-1. Ranges for Various Effects from 1 kT (ER and Fission) Weapons (100 m HOB or Surface Burst)

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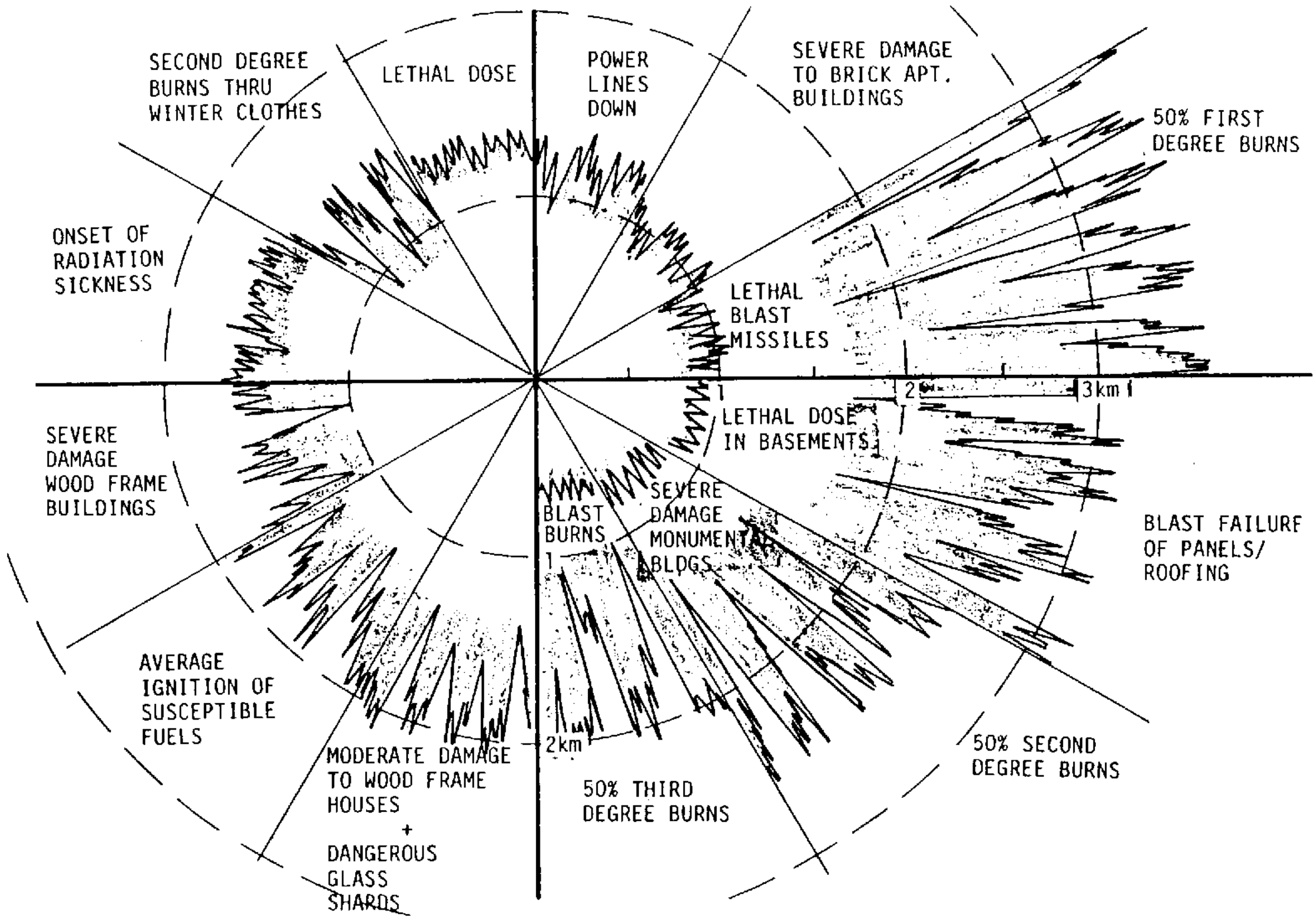

Figure B-2. Ranges for Effects from 10 kT Nuclear Burst (0-100m HOB)

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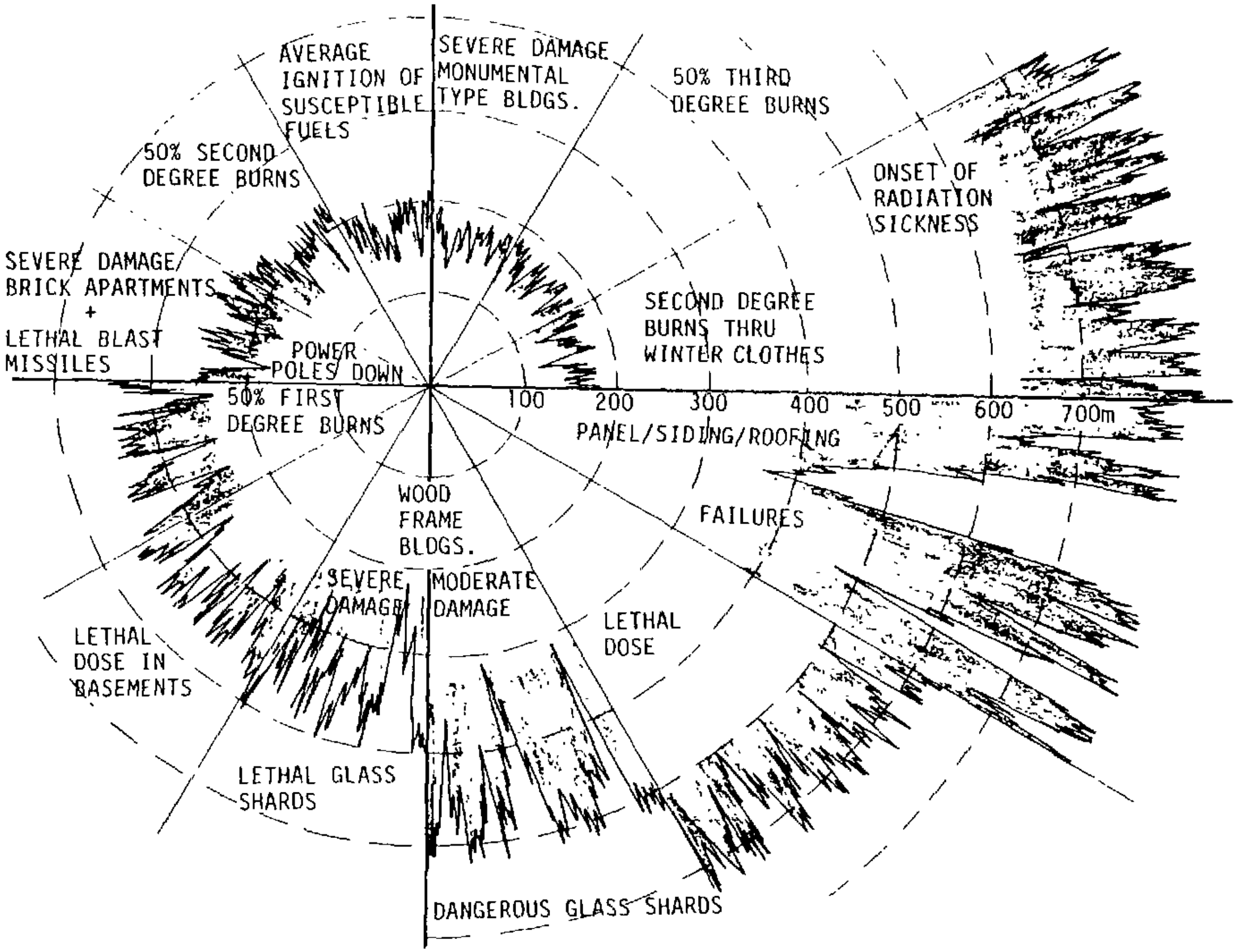

Figure B-3. Ranges for Effects from 100 Ton Nuclear Burst (0-100m HOB)

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Several serious hazards exist for people in the open beyond 2 km from 10 kT (Figure B-1), and beyond 1 km for a standard fission 1 kT weapon (Figure B-2). For a 1 kT ER warhead, lethal doses of prompt radiation extend beyond a kilometer, and represent perhaps the most serious threat to life from such weapons for exposed people. A lower yield also tends to make the nuclear radiation the dominant hazard. For 100 tons (Figure B-3), a lethal dose extends beyond a half kilometer, but relatively little serious physical damage can be expected at or beyond that range.

For severe damage to buildings, and so for injury to people indoors, the range is less than 1 1/2 km for 10 kT, 3/4 km for 1 kT, and 1/3 km from 100 kT. At 10 kT, however, many fires may be started even out beyond 2 km, while at 100 T, fires will be likely only inside of 1/4 km. At the smaller yields or from ER weapons, serious radiation doses will exist even inside houses at ranges twice that for severe structural damage.

More adequate protection can be found in basements and cellars, or in tunnels, sewers, storm drains, mines, and underground bunkers. In such shelter, people will be safe from all but a direct attack on their location. Massive amounts of earth cover or concrete and stone are needed for radiation shielding at the closest ranges. Attenuation factors of more than a thousand are needed to keep the dose below lethal levels within 1/3 km of a 1 kT ER weapon. A factor of 1000 attenuation could be expected behind 2 m of earth. Most basements provide radiation shielding of less than a factor of 10, but usually can be improved by judicious sandbagging of their most exposed aspects. Variations in basement shielding from house-to-house can be as much as factors of 3-5, and variations within a given basement can be as large.

Once the likelihood of nuclear conflict is evident, and the great value of shelter and shielding is recognized, very good shelter space will be identified, improved upon, improvised, or created and will be occupied by civilians during local battle, so that many local citizens are likely to survive even when their houses and towns become damaged or burned. As the realities of combat erode the restraints imposed by concern for avoiding collateral damage, and the military urgency of attacking enemy forces inside populated areas develops, the great value of good shelter may become the factor that makes it practical to destroy armored troops on the move without inflicting heavy loss of life on the indigenous population. Needless to say, the loss of property could be heavy, as it has so often been in battle zones.

The use of small yields and ER weapons can help to minimize this damage, and can still provide highly effective tactical nuclear weapons. However, since shielding is almost everywhere as available as dirt, and since troops under fire seek shelter in a hurry, there may be reason to rely on blast and fire effects to destroy military equipment when the men cannot be reliably stopped by radiation. In terms of weapon characteristics, this suggests that a purely radiation weapon with no blast and thermal might be less generally effective than a more balanced threat warhead--even though the "pure radiation" weapon would leave property and material untouched.

Some of the factors that make collateral damage constraints very uncertain are:

(1) The incomplete understanding of human response to lethal and sublethal levels of blast, thermal, and nuclear radiation.

(2) The variable influence of neutrons in causing different types of damage in humans--the relative biological effectiveness (RBE) for different syndromes.

(3) The role of combined injuries or insults to the human body in causing synergisms or responses greater than the sum of the consequences from individual injuries.

(4) The response to nuclear effects of a mixed population heavy with old people, the very young, and perhaps dominated by females. (Much of our current understanding is directed toward healthy young adult males.)

(5) The influence of wartime privations, including limited or no medical care or hospitalization, exposure to cold, malnutrition, poor sanitation, and disease. The normal increase of health hazards in such combat conditions can only be aggravated by exposure to nuclear radiation, but the extent of such complications is uncertain.

APPENDIX C. ACUTE RADIATION EFFECTS IN ANIMALS

Radiation as a militarily significant nuclear weapons effect was discussed by the Working Group primarily in terms of the animal data which has been generated by AFRRI. The AFRRI data base of radiation effects is based on animal experiments which have utilized several species. The most meaningful are those behavioral experiments using trained rhesus monkeys.

INCAPACITATION AS A BIOLOGICAL EFFECT

The observable behavioral response of the monkey to irradiation can vary from slight debilitation to complete prostration and death, depending on the dose received. For doses in the thousands of rads, three types of response are observed (Figure C-1). For most supralethal doses in which death is not immediate, the predominant response had been described as early transient incapacitation (ETI) (Figure C-1B). However, some animals continue to perform until death, with no period of recovery (Figure C-1A). Some last for hours to days (Figure C-1A), while others collapse within two hours (Figure C-1C).

There are several salient features of the transient incapacitation response (Figure C-1B). If one looks at the percentage of correct responses which an animal makes on a task as a function of time after a prompt dose of ionizing radiation, one can describe several characteristics of the response.

CHARACTERISTICS OF INCAPACITATION

1. Incapacitation is not immediate. Incapacitation is usually observed in about three to eight minutes after irradiation with a supralethal dose.

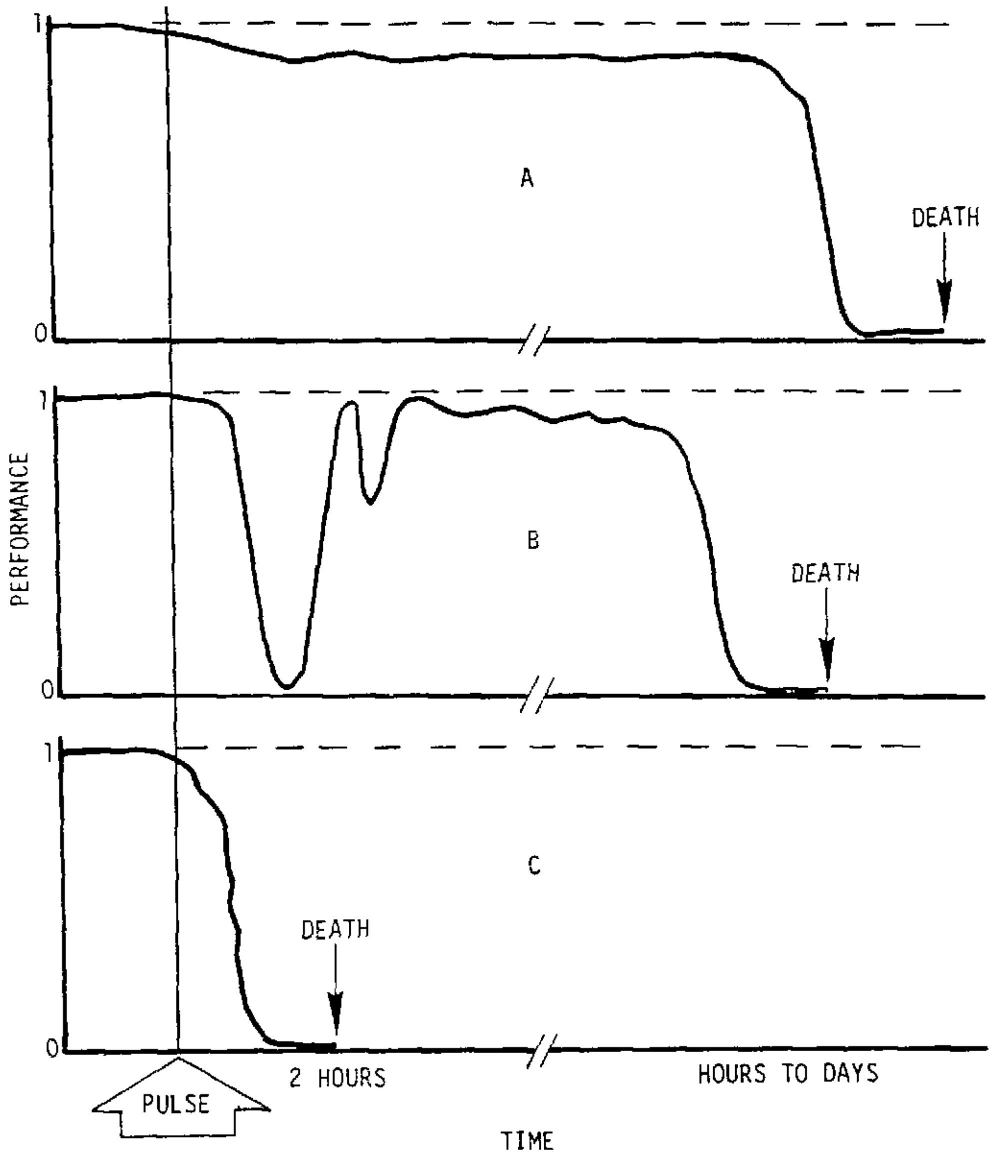

Figure C-1. Monkey Performance after Radiation

2. There is typically some period of inability to respond (incapacitation) followed by a recovery to a level which is usually slightly degraded from pre-irradiation levels of performance.
3. There may be one or more secondary periods of incapacitation.

All of these perturbations in the animal's performance typically occur within the first hour after exposure, after which a monkey typically continues to perform above the level defining "incapacitation," but may be degraded below the pre-irradiation levels, until shortly before death. Thus, the typical response of a monkey to supralethal irradiation is a period of transient incapacitation which begins several minutes after irradiation and from which the monkey has typically recovered within approximately a half-hour after exposure.

While the typical response to a dose of radiation is this transient incapacitation and temporary recovery for most of the subjects irradiated, some (as illustrated in Figures C-1A and C-1C) will be permanently incapacitated and not recover prior to death. As one might expect, the permanent incapacitation response increases as a function of dose. While some monkeys are not "incapacitated," they may suffer some degradation in performance. One often sees a lengthening in the time taken to respond to a task. That is, while the monkey may respond correctly to the task, the response time can lengthen significantly (Figure C-2).

TASK DEPENDENCY ON PERFORMANCE

Monkey response to irradiation has been expressed by measuring their performance of tasks they have been trained to perform.

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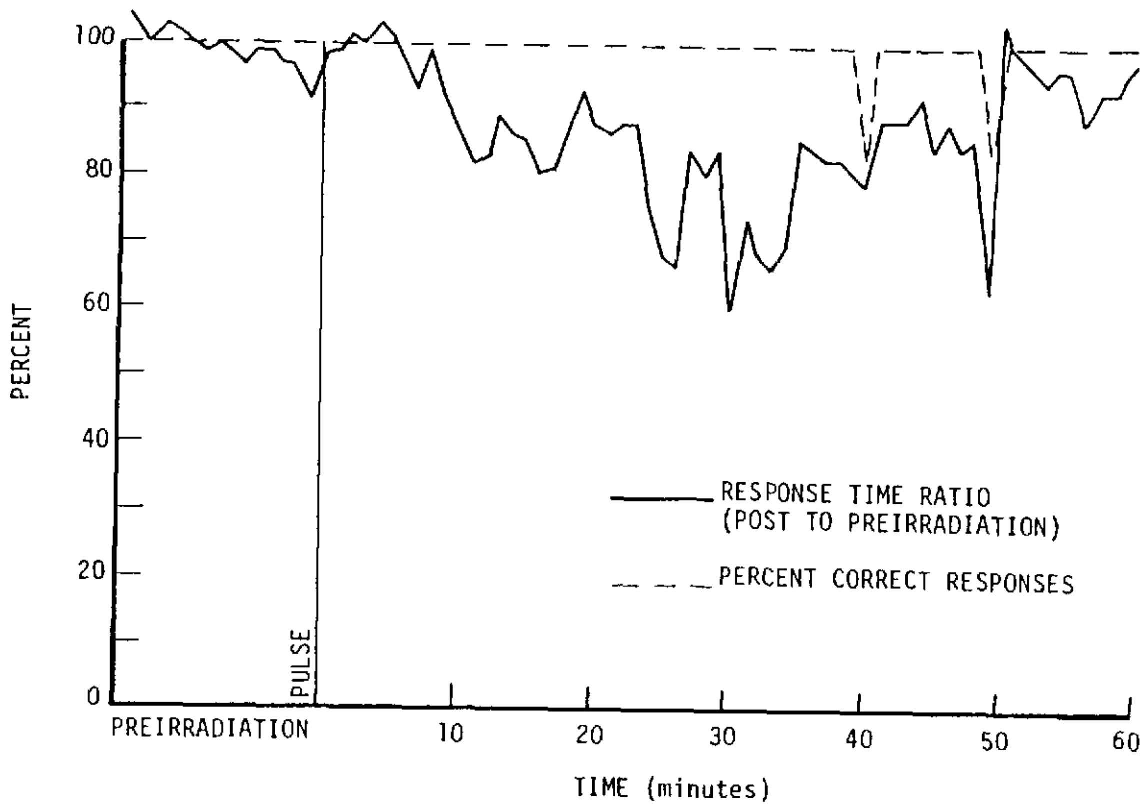

Figure C-2. Percentage of Correct Responses and Response Latency for the Unincapacitated Monkey after Irradiation

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Performance is recorded and the resultant data is studied for performance decrement as a result of irradiation. Radiation-induced performance decrement can vary from very slight increases in the time to respond to complete cessation of responding (for some specified period of time), or "incapacitation." In the AFRRI studies of the effects of radiation on performance, rhesus monkeys have been trained primarily to two tasks.

The first is a visual discrimination task in which restrained monkeys are trained to push a correct button in response to a lighted display key on repeated trials. Shock-avoidance is the motivation to select the correct of two geometric figures. In order to quantify the effects of radiation on the performance of this task, each trial is scored as either correct, incorrect, or an omission. The time to respond to each trial is recorded. This visual discrimination task is one which is primarily cognitive in nature, i.e., it requires mental processing to complete. Since the visual discrimination task models little of the physical activity involved in many military operations, the second task which is being studied at AFRRI is a physical activity wheel task.

In the physical activity wheel (PAW), the monkey is unrestrained and is required to run the activity wheel as a non-motorized treadmill. In this task, primates are trained to operate the cylindrical treadmill at a rate between two and three miles per hour. These animals are conditioned to maintain a 10-minute run/5-minute rest cycle for six hours. By observing the effect of radiation on these two tasks, the bulk of AFRRI's data concerning the effects of radiation on cognitive and physical performance has been generated.

OBSERVATION

The observation derived from the AFRRI animal work is that physical activity may be more severely affected by radiation than is cognitive activity.

This observation is emerging from a comparison of the work with the monkeys trained to the cognitive visual discrimination task and work currently under way employing a physical activity wheel task (C-1).* These results are preliminary and incomplete, but the results to date indicate that physical activity may be more severely affected by radiation than cognitive activity. However, these monkeys survive significantly longer after irradiation than those irradiated in the primate restraint chairs (visual discrimination animals). While these preliminary observations are suggestive of several militarily significant facts, they are not completely sorted out and will have to await the completion of the current investigations. There is, however, a significant body of experimental data from the visual discrimination task of relevance to tactical nuclear theater operations.

WHOLE BODY IRRADIATION

Dose Response

In order to define the basic dose response relationship for incapacitation in the monkeys as a function of radiation dose, 120 animals were irradiated in 6 dose groups ranging from mid-head doses of 800-5000 rads (1200-8000 rads free-in-air)

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*References are listed at the end of the appendix.

with a single, whole-body, unmoderated pulse from the AFRRI-TRIGA reactor (delivered to the back of the monkey). The radiation field employed for this study had a neutron-to-gamma ratio of 0.4 and was delivered to the animals in a single pulse having a pulse width of approximately 50 milliseconds. The results of this study provide the basic information concerning the response of the monkey to ionizing radiation in which performance is measured and radiation dose is the dependent variable. These data indicate that the relationship between dose, measured at the mid-head of the monkey, and the percentage of monkeys exhibiting incapacitation is described by a log normal function. This function describes the percentage of animals incapacitated for doses from 1200 to 8000 rads,* and fixes the median effective dose (ED_{50}) to produce incapacitation at approximately 2600 rads. If the dose is less than 3000 rads, the number of animals incapacitated increases sharply as the dose is increased (see Figure C-3). Between 3,000 and 8,000 rads, the instance of incapacitation only increases from 80 to 90 percent, an increase which is accounted for by an increasing number of early permanent incapacitations terminating in death (C-2) (see Figure C-3).

Emesis

In the process of collecting the behavioral performance data, we have also made certain gross clinical observations of the animals after irradiation. One set of these observations has been analyzed in such a way as to produce a dose response function for emesis (C-3). The findings of this study

*All doses are given in free-in-air terms, translated from monkey data by a single factor of 1.54 and translatable to human mid-head doses by a factor of 1.8.

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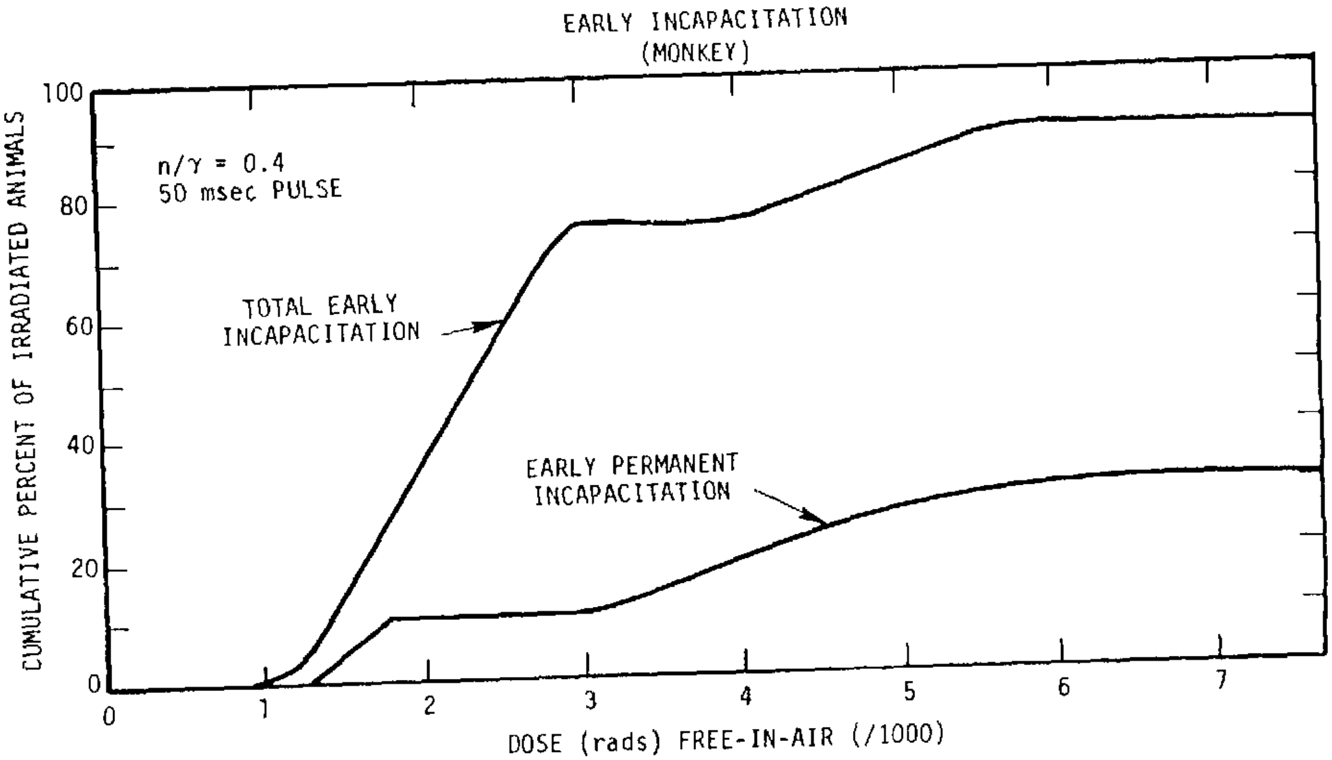

Figure C-3. Early Incapacitation

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indicate that the percentage of animals vomiting increases to a maximum of 80 percent at about 1500 rads. For doses above 1500 rads, the number of animals that vomited decreased as the dose was increased, so that for a dose of 8000 rads only 20 percent of the sample vomited. This decreasing incidence of emesis as dose was increased is accounted for by considering the severity of the incapacitations observed in these animals. As the dose was increased from 1500 rads to 8000 rads, the number of animals permanently incapacitated (early within the first two hours) increased from 0 to 30 percent. Among those animals which were permanently incapacitated, only one vomited. Thus, to generalize, as radiation dose is increased, the number of animals severely incapacitated increases. Severely incapacitated animals do not vomit.

Multiple Exposures

Due to combat conditions and the area coverage of nuclear weapons, multiple exposures of individual personnel are a valid concern for operational planning. In order to address this problem, several experiments have been conducted at AFRRI in which both miniature swine and monkeys have been irradiated with multiple exposures (C-4,5,6,7). In all of these studies, the split-dose technique was employed; that is, the subjects were irradiated with two fractions of some total dose. The effects obtained with the fractionated irradiation were then compared to those obtained from the same total dose delivered in a single dose. In all cases, the animals were exposed to pulsed doses of mixed neutron-gamma radiations using the normal field of the AFRRI-TRIGA reactor. With two exceptions, fractionated irradiations had less effect on behavior than the same dose delivered in a single pulse. This observation held for all intervals between fractions from 20 minutes to 51 hours, except for fractions separated by 40 minutes.

The effects of the radiation dose on behavior were decreased in all cases in which the dose was fractionated equally, but not for splits in which the initial fraction represented less than one-third of the total dose. While the research results suggest that the fractionation of a radiation dose diminishes its disruption of behavior, these studies are not exhaustive of the dose combinations and intervals between doses which could occur. Further, these studies are restricted to two fractions in which the lowest dose employed in any fraction was approximately an ED_{50} for monkeys.

PARTIAL BODY IRRADIATIONS

The research findings discussed thus far have dealt with whole-body irradiation. Other AFRRI studies have dealt with the militarily significant problem of partial body irradiations (C-8,9). The results of these studies indicate, for both mixed gamma-neutron radiation and LINAC-generated electrons, that shielding either the head or the trunk of the animal reduces, but does not eliminate, post-irradiation performance decrement. There was some evidence in the miniature pigs that head-shielding was more beneficial than trunk-shielding, but this finding has not been substantiated in two subsequent studies with the monkey. The overall suggestion of these studies seems to be that the greater the amount of protected tissue the less the radiation-produced effects on behavior.

DOSE RATE

In a single study of the effects of radiation dose rate on the behavior of the miniature pig, no significant difference in behavioral response could be detected until the dose was

delivered to the animal at a rate less than 2,000 rads per minute (C-10). Stated a different way, this study found no significant difference in behavioral decrement for pigs irradiated with a pulsed gamma field and the same field delivered at a rate of 2,000 rads per minute. The findings of this study are important in setting the lower limit on dose rate in which incapacitation is important.

RADIATION QUALITY

Perhaps one of the most significant findings to emerge from the animal work at AFRRI is the observation that neutrons are less effective in producing early behavioral incapacitation than are gamma photons (C-11,12). While neutrons produce significantly shorter survival times than gamma radiations (an observation consistent with commonly reported greater relative biological effectiveness of neutrons for producing tissue death), they produce significantly less behavioral disruption in the same animals prior to death. While this finding is unexplained at present, it has been replicated in four separate experiments with two animal species.

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APPENDIX D. CORRELATION OF RESPONSE TO ACUTE RADIATION BETWEEN SPECIES AND EXTRAPOLATION TO MAN

Predictions of the response of humans to prompt doses of nuclear radiation are based on data obtained from animal studies. Some extrapolations are necessary to relate this animal experience to what might be expected to occur in man. In the case of radiation-induced incapacitation, some problems exist which impact upon the confidence with which the animal data can be applied to man.

Radiation injury can be considered as a toxic insult, not unlike chemical and drug insults. In this light, there are two fundamental approaches to extrapolation of toxicity data from lower orders of animals to man--both are complimentary to each other, and neither is evidently superior to the other.

One approach requires knowledge of biological mechanisms as they operate in man, then finding an animal species that reacts to the insult in a comparable manner. One possibility is that acute radiation response is not organ specific, but that cell injury products (foreign compounds) are released into the blood stream, and that these in turn act on the central nervous system. This notion is supported by the observation that radiation-induced incapacitation occurs whether the head or trunk is irradiated, and that there is a definable cycle of behavioral effects.

Recognizing that a majority of foreign compounds undergo metabolic transformation, and that this biotransformation, in some instances, terminates the toxic effect and in other instances creates an even more toxic metabolite, it can be appreciated that a good animal model should be similar to man in at least

four respects: (1) the rates and routes of metabolism; (2) the rates and routes of excretion; (3) the pharmacokinetic profile; and (4) the receptor response (Smith, 1974) [D-1]. Since none of these factors possibly relevant to incapacitation are known, mechanisms cannot be used as a basis of extrapolation of radiation incapacitation data from animals to man. However, this approach represents a very fertile area for future research.

The second approach depends on phylogenetic progression as a basis for data extrapolation. In phylogenetic progression, diverse species from lower to higher branches on the evolutionary tree are exposed to the same insult, and responses are tabulated and examined for similarities and interrelations. Such conformality is demonstrated in Figure D-1, where the insult was anesthetic doses of amobarbital:

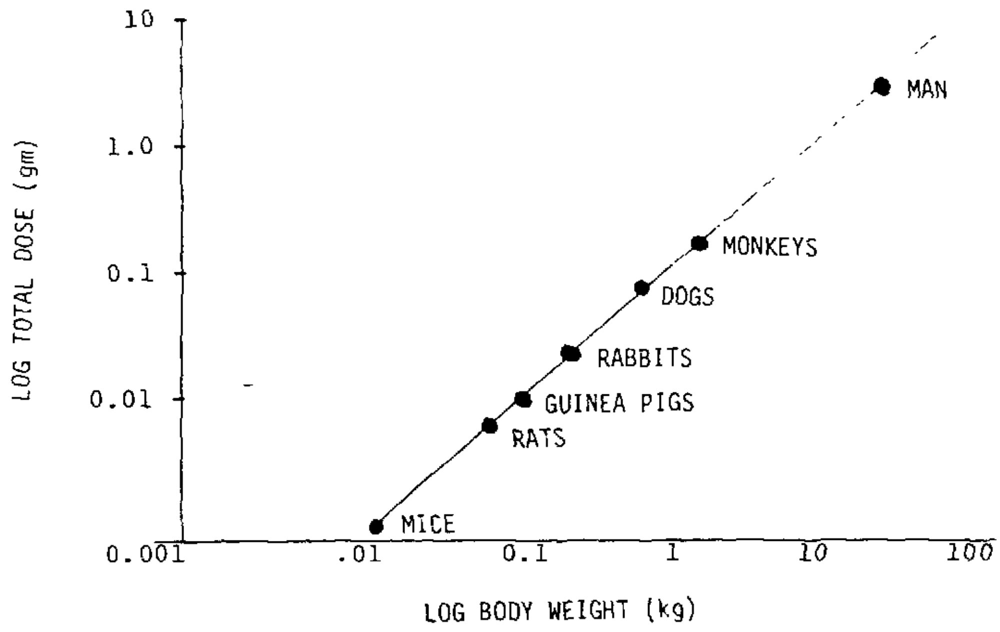

Figure D-1. Effective Doses of Intravenous Amobarbital Sodium

Correlation of diverse phylogenetic species behavior as in Figure D-1 generates a fairly high degree of confidence that man will fall near the extrapolation line, although with data from larger animals, a safer interpolation would be possible.

However, when reactions to a toxic agent are as diverse as represented in Table D-1, then there is obviously less basis for extrapolation to man. Note the wide disparity among carnivores, among rodents, and that a monkey is more like a chicken than any of the mammals tested.

Table D-1. Acute Toxicity of α - Naphthylthiourea in Various Species[a]

SPECIES	APPROXIMATE RELATIVE TOXICITY (RAT=1)
NORWAY WILD RAT	1
DOG	2
MOUSE	44
GUINEA PIG	44
RABBIT	>50
CAT	63
CHICKEN	313
MONKEY	532

[a]FROM SMITH, 1974 [D-1].

When the mechanisms of action in man are not understood, phylogenetic progression is the only alternative. But, if phylogenetic progression is disorderly, then one must return to basic mechanisms as the basis of extrapolation. This is because diverse reactions among diverse species points to a species-dependent mechanism for reaction to an insult, and one cannot safely extrapolate such response data to any other untested species.

Oftentimes, an insult will have the same qualitative effect across species, but will be quantitatively different. This implies that the same mechanisms are operating, but that there are species-dependent rate or ratio factors (rate of metabolizing a substance, or differential effects due to ratio of cholinergic vs adrenergic receptors, etc.). To clarify this principle, the following is quoted from Dr. Seevers (1966)[D-3] and is the result of several years of research on morphine-like substances in rhesus monkeys and man:

> In summary we can make a very definite statement based upon a comparison of approximately 60 of these compounds in monkey and man. We have not found any exception to the statement that the monkey and man are qualitatively similar in their response to this class of drugs. The word "qualitative" should be heavily underscored since quantitative predictions from monkey to man, except with derivatives of the morphine molecule itself, are not reliable. We can say without fear of contradiction, at this time, that if a drug will substitute in a morphine-dependent monkey, it will also show the same type of qualitative response in man.

When the substances have the same qualitative effects across numerous species, then a qualitative, descriptive extrapolation can more reasonably be made to other species. There are

a few observations (from accidents and therapy) for man, and these data agree qualitatively with animal data. The data are imprecise and unreliable, but generally span the curves extrapolated from animal models. As with any extrapolation, the further one moves from reliable (species specific) data, the greater the uncertainty or lack-of-confidence limits become.

In the radiation environment, high dose-rate accidents are the most relevant to the incapacitation question, since therapeutic cases are at relatively low dose rates and are from a select segment of the human population. At present, the totality of human data applicable to incapacitation is sparse and controversial and of limited value in evaluating models.

At the same time, a fair amount is known about radiation incapacitation in rhesus monkeys, and little is known about other species. The response of trained dogs to supralethal doses of radiation is neither qualitatively nor quantitatively similar to that of monkeys, miniature pigs or rats (Chaput et al, 1972, Ref. D-4). Miniature pigs are incapacitated at radiation intensities comparable to that needed for rhesus monkey incapacitation, but there are marked qualitative differences in that pigs are immediately incapacitated and have opisthotonic convulsions (Chaput and Wise, 1969, Ref. D-5), whereas monkeys are incapacitated several minutes after the pulse and have no convulsions. At present, there is sparse information on baboons, but it appears that they have the same qualitative syndrome as rhesus monkeys, but are quantitatively more sensitive (greater incapacitation for same 3000 rad midhead dose)(McMillan et al, 1972, Ref. D-6).

This disorderliness across diverse species indicates that radiation-induced incapacitation is importantly species specific due to currently unknown mechanisms. This is mitigated by the observation that the rhesus monkey (strong data) and the baboon (weak data) appear to have the same qualitative response to incapacitating radiation. In toxicology, there are a number of metabolic reactions that appear to be restricted in their species occurrences to man and other primates (Smith, 1974, Ref. D-1). If radiation incapacitation falls in this family of reactions, then a valid primate extrapolation model could be developed with some confidence.

It is also speculated that the greater sensitivity of the baboon to radiation incapacitation may be artifactual. It is known that animals of different sizes have significantly different energy distribution profiles. There is less degradation in dose across a smaller animal than across a larger one. However, in a larger animal exposed to a mixed neutron-gamma ray incident field, the fraction of the dose due to gamma radiation is larger because of capture gamma rays within the animal tissue. Further, to achieve the 3000 rad midhead dose in the rhesus monkey and baboon, the baboon had to be exposed to a greater free-in-air exposure than the monkey. Thus, the physical size of the specimen and the characteristics of the radiation environment significantly affect the dose distribution within the specimen.

Body shape may also be relevant, since small monkeys are very ectomorphic, having large surface area to volume ratios; the rhesis monkey is less so; and the baboon is quite mesomorphic, having a much lower surface area to volume ratio. Since there is a great difference in energy deposition when exposing a one-pound sheet or a one-pound block of substance to a radiation field, future extrapolation models may have to compensate for this effect.

CONCLUSIONS

1. There is currently so little known about the mechanisms of radiation incapacitation that extrapolation from monkey (small animals) to man remains unreliable. Experience with larger animals would be most helpful.

2. Pigs, dogs and rhesus monkeys are sufficiently species specific in their radiation incapacitation syndrome that, within the limits of present knowledge, only a gross extrapolation can be made to man, i.e., one can safely conclude that an incapacitation syndrome of some sort exists in man.

3. A small amount of incapacitation data for the baboon suggests that baboons and rhesus monkeys have similar incapacitation syndromes. This indicates a distinct possibility that an extrapolation model can be developed within the order Primata, making extrapolation to the human primate possible.

4. Although desirable, it is not necessary to understand how radiation energy is distributed within the body to develop a useful primate extrapolation model. What is necessary is to expose non-human primates of diverse species and sizes to radiation, and examine the data for some orderliness across species and across sizes. If reasonable correlations can be identified, then a common mechanistic basis can be presumed to exist, and reasonable extrapolations to man can be hypothesized.

RESEARCH RECOMMENDATIONS

It is strongly recommended that a detailed study of the basic nature of human incapacitation be undertaken to determine more precisely the nature and extent of post irradiation effects in combat and their military impact. Some more continuous measures of the effects of radiation on combat performance would be useful, and greater emphasis on the less immediate consequences also seems needed.

A detailed analysis of group interaction in armored operations is required, and this analysis must then be considered against the information gathered from human accident data as well as a broad range of animal models that explore post irradiation effects other than immediate incapacitation. These effects should include (but would not necessarily be limited to) nausea, vomiting, diarrhea and the high degree of fatigability. Such studies are essential to the development of more useful and realistic casualty criteria. They also may help to determine what a burdening dose of radiation is, so that more realistic and accurate predictions of rates of casualty production can be made.

It is recommended that a detailed study be performed to improve the present methods of extrapolating from research animal models to man in a combat environment. The present method based upon the assumption that the midline head dose is the most appropriate point of reference does not have adequate scientific justification and the potential impact of using the wrong point of reference in criteria development is extraordinarily significant. Consequently, this should be a high priority research requirement.

It is recommended that consideration be given to combined effects in all studies of radiation response or in the extrapolation of research or accident data to combat situations. A first step would be to analyze existing data on combined injury and to quantify the impact of other injury on the response to radiation. Past studies make it clear that significant interactions take place between radiation insults and a broad range of other stresses and injuries [D-7]. Studies over the entire spectrum of radiation doses from the supralethal (incapacitating) down to those which are of concern in troop safety and collateral damage are relevant. Analyses and studies done to date, including those to develop casualty criteria, have not considered combined injury adequately.

It has been suggested that even slight degradations in crew performance below their peak can have significant effects on battle effectiveness. Little experimental data address this question. Animal experiments to date have examined the effect of radiation on a range of performance indices from cognitive (image matching) to physical activity (treadmill/squirrel cage), but none of these studies has ever evaluated animals under conditions of peak performance. It can be inferred from the observed increases in time to respond to the tasks which have been tested after radiation, that peak performance could be heavily affected. Operational success is often predicated on peak performance in modern combat systems, and the effect of radiation on maximum performance should be of intense interest.

The existence of massive equipments of varying shielding effectiveness on the battlefield will produce a fair range of partial body irradiations from a weapon burst. Because the protective characteristics of shielding materials is different for blast, thermal and radiation energy, each of these effects has to be evaluated separately. Animal research indicates that shielding a portion of the body (either the head or the trunk) from radiations has a big effect in reducing the degree of incapacitation observed. These data indicate that trunk irradiation produces death much sooner than head irradiation, however. Based on these findings, it is unlikely that further partial body work would produce information of operational significance until more is known about the underlying mechanism of radiation incapacitation and death.

The large difference in body size between man and the primary experimental animal on which incapacitation data has been collected (the rhesus monkey) makes the direct extrapolation of these data difficult and uncertain. No precise knowledge as to mechanism underlying incapacitation exists, so the point within a zoological specimen at which the radiation dose should be measured or referenced cannot be assured. For these reasons, considerable uncertainty is introduced in relating the rhesus monkey experience to that expected for man. Measuring the mid-head dose, as has been the common practice in the experimental work with monkeys, or a surface free-in-air dose, as has been the practice in most operational specifications, seem equally inadequate to the current extrapolation problem.

Several factors contribute to this dilemma. First, the reference point (mid-head) in the monkey, while significant, is not as significant as that for the much larger species, man, in whom the radiation is much less uniformly distributed.

Second, the greater tissue volume of man produces more capture gamma radiation than the monkey, resulting in a greater whole-body gamma dose for humans. Since gamma radiations are more effective in incapacitation, this difference produces a potentially significant nonlinearity in favor of incapacitation of man at lower doses when an extrapolation is made. Third, the greater tissue volume of man requires a larger surface dose to result in the same midhead dose, thus producing a greater whole body radiation in man.

These observations are pointed up in the work by McMillan et al (1972) [D-6] in which baboons, a larger primate, exhibited qualitatively similar but quantitatively greater performance decrements than rhesus monkeys when both were irradiated with the same 3000 rad midhead dose. While this result could represent a species difference in the primate response, it more likely reflects the fact that the baboon has a larger head tissue mass, which required a larger free field dose to produce the equivalent midhead dose. These data and observations suggest that larger species primate research is required in order to make the extrapolation from monkey to man with greater confidence.

The relative biological effectiveness (RBE) of neutrons in producing behavioral incapacitation is less than one for both the monkey and the miniature pig. Neutrons are more effective in producing death, however. That is, incapacitation after neutron radiation will be less than for an equal dose of gamma radiation, but the survival times will be significantly shorter. The extrapolation of this observation to man is reasonable in light of the consistency of the observation across species. As applied to military operations, this observation has two potentially significant impacts. First, there are the obvious

implications of a weapon's effectiveness as a function of the spectrum which it produces. Rad for rad, the neutrons that a weapon produces would be less effective than the gamma rays in causing incapacitation in assault troops.

Second, and potentially as important, is the effect of RBE on the extrapolation from the rhesus monkey to man. Since a man represents a considerably larger cross-sectional area than a monkey, there will be greater capture gamma production in man resulting in a greater overall whole body gamma dose. Thus, man could be incapacitated at a lower dose than the monkey data currently suggest. Experiments to investigate this possible consequence of RBE and body size should be encouraged.

In some of the monkeys which did not exhibit incapacitation after irradiation, the response time of the monkey (latency) lengthened significantly. This observation means that there is impairment of the performance in animals which are not incapacitated in the terms of the experimental definition. The fact that these data were derived from monkeys performing tasks which allowed ample time in which to respond to the task, and did not require maximum or peak performance, implies that the dose to incapacitate could be significantly reduced. Experiments are needed which measure the delays in response induced by radiation exposure when an animal is being forced to perform at or near his maximum. Where possible, existing data from previous experiments should be analyzed to retrieve and document the induced delays, even at less than peak performance.

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APPENDIX E. ARMY/JCS RADIATION CASUALTY CRITERIA

SECTION 1

1. GENERAL CONSIDERATIONS FOR CASUALTY CRITERIA.

a. Casualty. Casualty criteria are normally levels of effects at which half of the personnel exposed to those levels become casualties. For weapons employment considerations, a casualty is defined as a person who is unable to perform his assigned task. Since the selection of a particular weapon and yield for tactical employment depends in no small measure on the distance to which the governing casualty producing mechanism extends, it is advantageous to use one consistent definition for casualty which is applicable to all of the casualty producing mechanisms. Unfortunately, difficulties arise in numerically determining via experiment just what is required for an individual to become a casualty. For example, a nuclear radiation casualty is defined as a person who is able to perform only at 50 percent or less of his pre-irradiation performance level, whereas a casualty resulting from airblast-induced tumbling is a person who sustains at least one severe injury, e.g., a fracture or the rupture of an internal organ. These definitions result, to some extent, in comparing "apples and oranges" when deciding which mechanism governs. Determining incidences of "combat ineffectiveness" (CI) is one attempt at equalizing the varied bases among experimental determinations of casualty incidences. However, the prospect of comparing casualty producing mechanisms on co-equal bases is further rendered improbable by the singular manner in which time impacts the production of radiation casualties and, to a lesser extent, thermal casualties.

b. Time to Ineffectiveness. It is still true that there is a time dependence in the development of casualties from nuclear weapons effects. However, it is now recognized that it is more constructive to understand the role played by this time dependence than to develop criteria bound to any particular set of times. It follows then that it is not essential for criteria to focus solely on permanent casualty production by prescribed times.

2. INITIAL NUCLEAR RADIATION CASUALTY CRITERIA.

a. Relative Biological Effectiveness.

(1) The relative biological effectiveness (RBE) is a factor which expresses the relative effectiveness of different types and energies of radiation to produce a given biological effect. The RBE depends upon, among other things, the type and energy of radiation involved, the total dose received, and the dose rate.

(2) In this addendum, the term RBE means the effectiveness of fission-spectrum neutrons relative to fission-spectrum gamma rays for affecting the central nervous system to the extent that behavioral responses are degraded. The RBE is further constrained in this addendum to apply only to supralethal doses (> 1,000 rads) of radiation.

(3) This addendum continues the PRCC* assumption that the neutron RBE is unity, but for slightly different reasons. The PRCC states:

"No valid quantitative results exist for demonstrating that the neutron RBE for producing incapacitation is different from unity in the monkey."

However, recent experiments have indicated that the neutron RBE is not unity. Although preliminary evidence points to a value of approximately 0.6, at this time there are not enough data available to quantitatively and reliably confirm the value. Therefore, the assumption that the neutron RBE is unity has been continued in this work because insufficient evidence exists for ascertaining a neutron RBE different from unity for producing incapacitation in the monkey.

b. Neutron-to-Gamma Ratio.

(1) In discussing mixed neutron-gamma radiation fields, the relative amount of each type of radiation is specified by the neutron-to-gamma ratio. The ratio is defined as the neutron dose (rad-tissue) divided by the gamma-ray dose (rad-tissue).

* Personnel Risk and Casualty Criteria for Nuclear Weapons Effects Study, 2 August 1971 (Reference E-1).

(2) Two details require the specification of the neutron-to-gamma ratio when presenting radiation casualty dose levels for use in mixed radiation fields. First, neutrons and gamma rays are attenuated differently in matter; therefore, the same incident dose in rads for two differently comprised radiation fields usually results in different doses in rads inside an exposed object. Second, the existence of a neutron RBE requires that strict accounting be maintained of the neutron portion of an absorbed dose so that the appropriate RBE can be applied.

(3) While radiation casualty dose levels are expressed in free-in-air doses, they are developed from midhead doses. The procedure used to determine the free-in-air dose which results in any particular midhead dose must assume a value for the incident neutron-to-gamma ratio. The consequence is that, strictly speaking, the casualty dose levels are valid only for the assumed incident neutron-to-gamma ratio.

(4) At ranges of interest, reasonable incident neutron-to-gamma ratios are on the order of 3:1. Thus, unless stated otherwise, all radiation casualty criteria presented in this addendum have been developed for exposures in mixed neutron-gamma radiation fields with incident neutron-to gamma ratios of 3:1. Paragraph 3e of Section 2 presents a methodology which allows transformation of free-in-air dose levels developed for mixed radiation fields with a neutron-to-gamma ratio of 3:1 to the appropriate free-in-air dose for any other mixed neutron-gamma radiation field, and vice versa

(5) For the case where the neutron RBE equals unity, the resulting casualty criteria are relatively insensitive to the value of the neutron-to-gamma ratio. The transformation function varies from 1.01 for pure neutron fields to 0.97 for pure gamma ray fields.

c. Task Dependency. The PRCC contains the statement:

> "Task dependency cannot reasonably be incorporated into radiation response predictions at the present time. The behavioral tasks used to measure radiation response of laboratory animals have been relatively crude, and task dependency of radiation response has not been determined."

Since the time that that statement was made, the Physical Activity Wheel (PAW) task was developed and put into operation at the Armed Forces Radiobiology Research Institute (AFRRI). The PAW task requires a monkey to run at his natural pace inside of a large squirrel wheel for ten minutes, then rest for five minutes, repeating this cycle for a continuous six hour period. The monkey's speed and the number of revolutions are recorded. As in previous tests, the stimulus is cued shock avoidance, i.e., failure to perform the task results in administration of an electrical shock. Initial results of the PAW task demonstrated that some dose levels at which test animals were able to successfully perform the visual discrimination (physically undemanding) task were too high for the animals to successfully perform the more arduous PAW (physically demanding) task. Experimentation with the PAW task is continuing and the data available at the time of the addendum's preparation have been used to establish the physically demanding criterion. That criterion is considered applicable to soldiers performing normal combat duties.

d. Additional Human Radiation Accident. In June 1974, a radiation worker at an industrial plant in New Jersey accidentally received a whole body dose of approximately 600 rads (450 rad average bone marrow dose) from a cobalt-60 (gamma) source. The victim exhibited prodromal symptoms (specifically nausea and vomiting) of acute radiation sickness, commencing some 30 to 60 minutes post-exposure. During the 2-1/2 to 3 hours that elapsed between the exposure and the victim's arrival at the hospital emergency room, he experienced ten episodes of vomiting. He was described as being concerned, but not unduly anxious, about his condition (it was further stated that he was the calmest individual in the hospital emergency room). In the days following his admission to the hospital, his white blood cell and platelet counts steadily decreased. During the 22nd to 35th days post-exposure, his blood count had dropped so low that only the large numbers of transfused platelets and granulocytes maintained his life. After the 35th day, his condition improved rapidly; he was discharged from the hospital on the 45th day and subsequently returned to full-time work.

e. Changes in Monkey Response Data Base.

(1) Since radiation response is task dependent, it is recognized that casualty response summary curves must be developed for animal populations performing identical tasks. For this reason, the data from the 1965 WRAIR study were removed from the data base previously used in the PRCC to determine casualty dose levels.

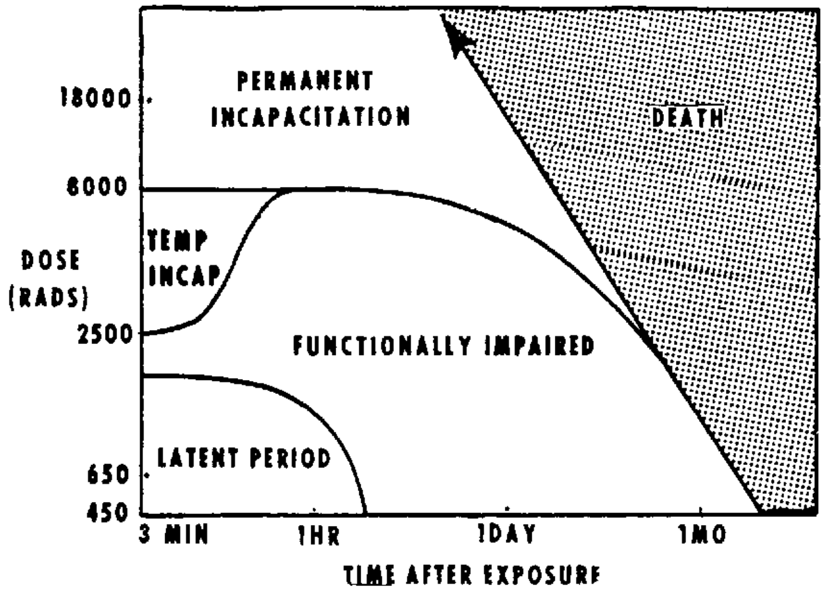

FIGURE E-1. PHYSICALLY DEMANDING

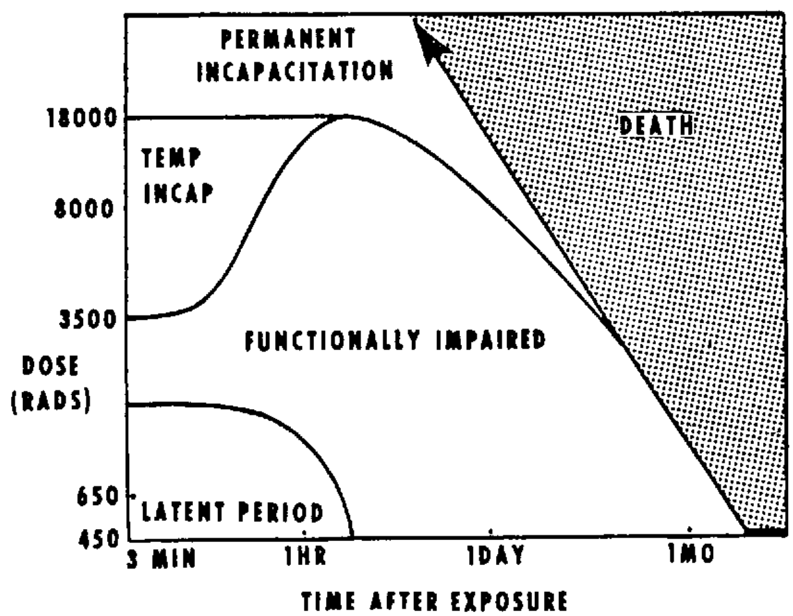

FIGURE E-2. PHYSICALLY UNDEMANDING

(2) Response data for all of the monkeys performing the PAW task have not yet been published by AFRRI (reference E-2). Preliminary data have been made available to USANUA and the results of the analysis of those data are presented.

f. Analysis. De-emphasizing the predetermined times to permanent ineffectiveness, examining in detail the expected responses of exposed personnel, and recognizing the biological variability associated with radiation exposures led to the development of four new initial nuclear radiation casualty criteria. Figures E-1 and E-2 schematically portray man's expected response to casualty-producing doses of nuclear radiation.

(1) Section 2 presents the methodology developed for the extrapolation of monkey response data to human casualty dose levels. This methodology supersedes that contained in the PRCC.

(a) Definitions.

1. Incapacitated personnel are those who perform at 50 percent or less of their pre-irradiation performance level. Incapacitation is manifested by shock and coma at the high dose levels. At lower dose levels, incapacitation is manifested by a simple slowing down of the rate of performance due to loss of physical mobility and/or mental disorientation.

2. Functionally impaired personnel are those who, while not incapacitated, will exhibit a decreased ability to perform their assigned tasks. These personnel will suffer radiation sickness in varying degrees of severity and at changeable times. Radiation sickness will be manifested by various combinations of projectile vomiting, propulsive diarrhea, 'dry heaving', nausea, lethargy, depression and mental disorientation. Although these effects will be transitory, whenever an individual is experiencing them, he generally will be unable to perform his assigned task. In any case, performance levels will be lower than pre-irradiation performance levels and will decrease slowly until either the individual begins to recover or dies, usually with a precipitous decline occurring just prior to death.

(b) Probit analyses of the midhead radiation doses required to produce immediate permanent incapacitation and immediate transient incapacitation were performed in the manner described in the PRCC. The results of those analyses are presented in figure E-3. These relationships for midhead doses can be transformed to those for free-in-air doses using the procedure described in paragraph 3d of Section 2. The results of that transformation are included in figure E-3 as dashed lines. From this figure, one concludes that the dose levels contained in table E-1 could be considered candidate criteria:

Table E-1 Candidate Criteria

Free Air Dose	Effect
18,000 rads	Immediate permanent incapacitation for personnel performing physically undemanding tasks.
8,000 rads	Immediate permanent incapacitation for personnel performing physically demanding tasks.
3,000 rads	Immediate transient incapacitation for personnel performing physically undemanding tasks.
2,000 rads	Immediate transient incapacitation for personnel performing physically demanding tasks.

(c) An examination of the Casualty Response Summary Curves (figures E-4 and E-5 in Section 2) show that a radiation dose of 2,000-3,000 rads causes an immediate (within 5 minutes), complete incapacitation for a period of 30 to 40 minutes followed by a recovery period during which personnel are functionally impaired. Death will occur in approximately 5 days. Thus, <u>a dose of 3,000 rads produces immediate temporary casualties, each one of whom may be considered as ineffective in performing his assigned combat tasks, regardless of how physically demanding they are</u>.

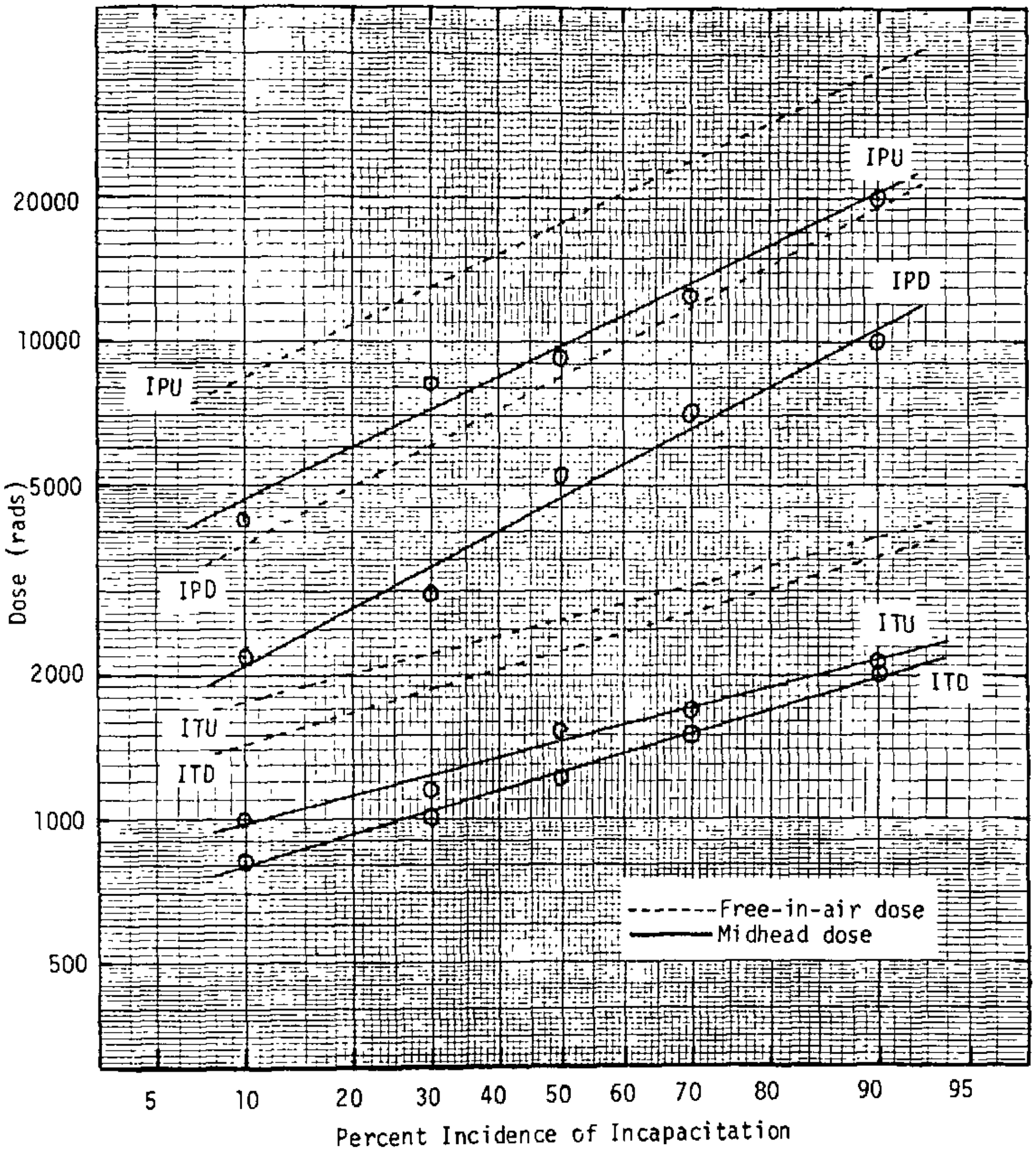

Figure E-3 Probit Analyses--Radiation-Induced Incapacitation

(d) A general review of personnel tasks performed in active combat reveals that nearly all require some degree of physical activity such as running, walking, or lifting. Thus, a dose of 8,000 rads should be almost always adequate for producing immediate and permanent casualties when immediate but temporary casualties (3,000 rads) are not sufficient. For those few cases where an individual might have some significant impact on a battle by merely pressing a button (a physically undemanding task) after recovering from the immediate, but temporary effects induced by radiation doses of 3,000 rads, 18,000 rads can be used as the criterion for precluding the accomplishment of even the physically undemanding task. However, the vulnerability of the equipment should also be considered, since the blast and thermal effects which occur at the same distance from the burst point as 18,000 rads may have rendered the equipment inoperative.

(2) Radiation levels considered in previous paragraphs are characterized by the immediate response of the individual to the dose. Although there may be some recovery after the initial incapacitation, for the levels considered, the average individual will never again be able to perform at his baseline performance. It is recognized that there may be situations where such stringent criteria are not required for mission accomplishment. In those cases when immediate incapacitation is not required before the individual lapses into the functionally impaired domain (such as reserve or support troops), a radiation dose of 650 rads can be used as a criterion. This criterion is based upon data from the irradiation of cancer patients, using the limited human accident data as checkpoints. Typically, the response to this dose is nausea, vomiting, diarrhea, headaches, and lethargy. Nearly all the exposed population will experience nausea and vomiting within 2 hours after exposure with the symptoms continuing intermittently for the next few days. Personnel will require hospitalization for treatment such as the administration of anti-emetics, preventive antibiotics, and intravenous fluid replacement. From the second to the sixth day, the individual will be easily fatigued and experience malaise and headaches. Generally, severe diarrhea will develop about 6 days after exposure. More than half the exposed individuals will die as a direct consequence of the radiation even if they are hospitalized. The mean survival time for an individual who dies is about 16 days. A dose of 650 rads produces latent casualties of sufficient magnitude and severity to degrade the effectiveness of any unit.

g. Conclusions. Based on the best information available, the appropriate radiation doses for casualty criteria are 18,000, 8,000, 3,000, and 650 rads. These doses produce casualties described below:

(1) Immediate Permanent (IP) Incapacitation.

(a) 18,000 rads. Personnel will become incapacitated within 5 minutes of exposure and for any task will remain incapacitated until death. Death will occur within 1 day.

(b) 8,000 rads. Personnel will become incapacitated within 5 minutes of exposure and for physically demanding tasks will remain incapacitated until death. Death will occur in 1-2 days.

(2) Immediate Transient (IT) Incapacitation. 3,000 rads. Personnel will become incapacitated within 5 minutes of exposure and will remain so for 30-45 minutes. Personnel will then recover but will be functionally impaired until death. Death will occur in 4-6 days.

(3) Latent Lethality. 650 rads. Personnel will become functionally impaired within 2 hours of exposure. Personnel may respond to medical treatment and survive this dose, however, the majority of exposed personnel will remain functionally impaired until death in several weeks.

h. Comparison of Results. The radiation casualty criteria developed in the PRCC are presented in table E-2 and the criteria developed in this addendum are presented in table E-3.

Table E-2 PRCC Radiation Casualty Criteria

Time to Ineffectiveness	PRCC Radiation Casualty Criterion (rad)*
15 minutes	19,000
1 hour	14,000
4 hours	12,000
8 hours	11,000
24 hours	5,000

*Midline dose (free-in-air)

Table E-3 New Radiation Casualty Criteria**

Dose (rads)*	Descriptor
18,000	Immediate Permanent (Undemanding)
8,000	Immediate Permanent (Demanding)
3,000	Immediate Transient
650	Latent Lethality

* Midline dose (free-in-air) for an incident neutron-to-gamma ratio of 3:1.

** These criteria were approved by the Joint Chiefs of Staff on 12 May 1975 for use by all US Armed Forces in nuclear weapons target analyses and selection procedures for land battlefield targets.

SECTION 2. THE CALCULATION OF NUCLEAR RADIATION CASUALTY DOSE LEVELS

1. PURPOSE AND SCOPE. The manipulations for converting the data resulting from performance degradation experiments conducted with monkeys to casualty dose levels applicable for determining human casualty criteria are very complex. Previous efforts addressed the problem piece-meal without adequate documentation of the many details of the procedures and calculations. It is the purpose of this appendix to record the procedure followed, assumptions used, calculations performed, and results obtained in the determination of nuclear radiation casualty dose levels. The approach used in this appendix is to trace the thought processes, state assumptions as they are made, and perform the calculations whenever they are required.

2. GENERAL. Some useful general concepts are presented in this paragraph.

a. The subscripts used in the equations in this appendix are defined as follows:

n - neutron.

g - gamma ray.

e - external (or incident).

i - internal (usually the midhead position).

h - human beings.

m - monkeys.

b. Neutron-to-gamma ratio, f. In discussing a mixed neutron-to-gamma radiation environment, it is useful to describe the relative constitution of the radiation field by the neutron-to-gamma ratio. The ratio is defined here as the neutron tissue dose in rad divided by the gamma-ray tissue dose in rad. For the purposes of this appendix, it is important to note that the term 'neutron dose' refers to absorbed dose arising from neutron interactions in tissue less the dose due to capture gamma rays, the latter being included in the term 'gamma-ray dose'. A more detailed discussion of radiation doses is found in reference E-3.

$$f = \frac{\text{neutron tissue dose in rad}}{\text{gamma-ray tissue dose in rad}}$$

c. Neutron and gamma fractions, F_n and F_g, are calculated from the neutron-to-gamma ratio.

$$F_n = \frac{f}{1 + f} \qquad [1]$$

$$F_g = \frac{1}{1 + f} \qquad [2]$$

d. Transmission factor, TF. The transmission factor reflects any net attenuation or buildup of incident radiations that occurs while traveling through a medium. Thus, the transmission factor is defined as the ratio of the dose at a specified position in the medium after the radiation has passed through the medium to the free-in-air dose. A transmission factor is a function of the energy spectrum of the incident radiation, the composition of the attenuating medium, the geometry of the medium, and the depth of interest into the medium that the radiation travels; it is not usually considered a function of the incident neutron-to-gamma ratio. As a consequence of the physical processes that occur when neutrons pass through tissue, gamma rays originate within the tissue; these gamma rays are referred to as capture gamma rays. Since dosimeters do not distinguish between attenuated gamma rays from the incident radiation and capture gamma rays, a measured dose reflects both. Further, the more neutrons there are present in the incident field, the more gamma rays there will be present for detection inside the medium; thus, the measured gamma-ray transmission factor for an incident mixed neutron-gamma radiation field will be greater than if the field consisted solely of gamma rays -- and, in fact, the value can be even greater than unity. In mixed neutron-gamma radiation fields it is, therefore, convenient to consider the gamma-ray transmission factor as a function of the incident neutron-to-gamma ratio and

the energy spectrum of the incident neutrons as well. Current calculations* result in the following transmission factors (to the midhead position) appropriate for men exposed to nuclear weapon radiation environments and for monkeys exposed in AFRRI pulse reactor experiments.

(1) Transmission factors for humans:

$$TF_n = 0.51$$

$$TF_g = 0.54 + 0.05f_e$$

(2) Transmission factors for monkeys:

$$TF_n = 0.81$$

$$TF_g = 0.92 + 0.12f_e$$

e. Total dose, D. In this appendix, D_e refers to the total free-in-air tissue dose (incident dose) expressed in rad at a specified value of f_e; D_i refers to the total tissue dose at the midhead position expressed in rad arising from a specified value of f_e.

f. Relative Biological Effectiveness, RBE. The relative biological effectiveness is a factor that expresses the relative effectiveness of differing radiations for producing a given biological effect. In this appendix, the term RBE is constrained to mean the effectiveness of fission-spectrum neutrons to degrade one's ability to perform assigned tasks relative to that of fission-spectrum gamma rays.

g. Biological equivalent dose, H. The biological equivalent dose is expressed in rem (a rem is a unit of <u>dose equivalent</u> which is numerically equal to the dose in rad multiplied by appropriate modifying factors, e.g., the RBE):

$$H = (F_n\ RBE + F_g)\ D$$

3. DEVELOPMENT OF THE PROCEDURE. The responses of supralethal doses of radiation of human beings and monkeys (*Macaca mulatta*) performing equivalent tasks have been assumed to be the same for identical midhead biological equivalent doses. The midhead rem dose, H_i, is defined by the following equation:

$$H_i = (F_{ni}RBE + F_{gi})\ D_i \qquad [\ 3\ ]$$

Making the adjunct assumption that the RBE is not species dependent but only a function of the radiation, leads to the requirement that for the same radiation response,

$$D_{ih}(F_{nih}RBE + F_{gih}) = D_{im}(F_{nim}RBE + F_{gim}) \qquad [\ 4\ ]$$

Note that equation [4] is a general relation for applying the assumption regardless of the radiation environment of the man and/or the monkey. Simple rearrangement leads to an expression relating man's midhead dose in rad to the monkey's midhead dose in rad:

$$D_{ih} = \frac{F_{nim}RBE + F_{gim}}{F_{nih}RBE + F_{gih}}\ D_{im} \qquad [\ 5\ ]$$

At this point, it becomes important to recognize that, while the above equation reflects the base assumption, it does so in terms of quantities that are neither measured experimentally nor reported by researchers. Specifically, the various radiation fractions must be determined in terms of normally reported quantities, i.e., transmission factors and incident neutron-to-gamma ratios.

a. Conversion from Midline Tissue Dose to Midhead Dose. Within the limitations incurred by extrapolation from monkey response to human response, to properly develop casualty dose levels requires that midhead doses be used. Most reports of experiments conducted at AFRRI record the administered radiation in terms of midline tissue doses. These midline tissue doses are converted to midhead doses by multiplying the factor 1.07 (reference E-4..

*Descriptions of these calculations can be found in reference E-3. The short discussion contained in Appendix B of the PRCC is also of value.

b. Neutron and Gamma Fractions. Reasonable external neutron-to-gamma ratios at distances where radiation is the dominant casualty producing mechanism are on the order of 3:1. For that reason, and unless stated otherwise, all radiation casualty dose levels and criteria presented in this study are developed for a man exposed to a mixed neutron-gamma radiation field with $f_e = 3.0$. Using the transmission factors, the neutron and gamma fractions are calculated as follows:

$$d_{ni} = F_{ne} TF_n D_e \qquad [6]$$

$$d_{gi} = F_{ge} TF_g D_e \qquad [7]$$

where:

d_{ni} = midhead dose due to neutrons (rad).

d_{gi} = midhead dose due to incident and capture gamma-rays (rad).

Since by definition, $f_i = d_{ni}/d_{gi}$, equation [1] can be rewritten as:

$$F_{ni} = (d_{ni}/d_{gi})/[(d_{ni}/d_{gi}) + 1] \qquad [8]$$

Substituting equations [1], [2], [6], and [7] into equation [8] and rearranging terms gives the result:

$$F_{ni} = \frac{f_e TF_n}{f_e TF_n + TF_g} \qquad [9]$$

(1) Using the transmission factors for humans presented in **paragraph 2d(1)** with $f_e = 3.0$ to evaluate equation [9] results in $F_{nih} = 0.69$, $F_{gih} = 0.31$, and $f_{ih} = 2.23$. In other words, a man exposed to a mixed neutron-gamma radiation field with a neutron-to-gamma ratio of 3:1 will have a mixed neutron-gamma radiation field at the middle of his head with a neutron-to-gamma ratio of 2.23:1.

(2) Most experiments conducted with monkeys at AFRRI exposed the monkeys to mixed neutron-gamma radiations with incident neutron-to-gamma ratios of 2:5 or 3:1. Solving equation [9] with the transmission factors for monkeys gives the following results:

(a) Case I. $f_e = 0.4$

$$F_{nim} = \frac{(.4)(.81)}{(.4)(.81) + .92 + (.12)(.4)} = 0.25$$

Therefore, for monkeys with $f_e = 0.4$; $F_{ni} = 0.25$, $F_{gi} = 0.75$, and $f_i = 0.33$.

(b) Case II. $f_e = 3.0$.

$$F_{nim} = \frac{(3)(.81)}{(3)(.81) + .92 + (.12)(3)} = 0.65$$

Therefore, for monkeys with $f_e = 3.0$; $F_{ni} = 0.65$, $F_{gi} = 0.35$, and $f_i = 1.86$.

(3) Hence, a monkey exposed to a mixed neutron-gamma radiation field with incident neutron-to-gamma ratio of 2:5 has a midhead neutron-to-gamma ratio of 1:3, but if the incident neutron-to-gamma ratio were 3:1, the midhead neutron-to-gamma ratio would be 1.86:1. *Significantly then*, if a man and a monkey are both exposed to identical mixed neutron-gamma radiation fields, they will have different fields at their respective midhead positions <u>due solely to differences in the attenuation</u> of the mixed radiations. Specifically, neutrons and gamma rays are attenuated differently and the difference between the results for men and monkeys arises from their different head sizes.

c. Casualty Response Summary Curves. The techniques used to construct the Casualty Response Summary Curves are well described in the PRCC. Such curves must be constructed separately for both the physically demanding and undemanding tasks. A difference between the technique used here and in

the PRCC is that in this appendix the curves are drawn using the midhead doses (rad) to men and that result in the same midhead biological equivalent doses (rem) to both the men and the monkeys, rather than simply using the midhead doses (rad) to monkeys. This procedure allows the explicit accounting for neutron RBE.

d. Transformation to Free-in-Air Doses. Casualty dose levels must be transformed to the appropriate free-in-air dose levels for an incident radiation field with a neutron-to-gamma ratio of 3:1; i.e., D_{ih} has been determined and D_{eh} is required. These quantities can be related by using equations [6] and [7] to give:

$$D_{eh} = D_{ih}\left[\frac{1}{F_{ne}TF_n + F_{ge}TF_g}\right] \qquad [\ 10\ ]$$

For $f_e = 3.0$, $F_{ne} = .75$, and $F_{ge} = .25$, thus:

$$D_{eh} = D_{ih}\left[\frac{1}{(.75)(.51)+(.25)(.54 + (0.5)(3))}\right] = 1.80\ D_{ih}$$

e. Application of Results to Other Radiation Fields. The transformation function, α, accounts for both the neutron RBE and attenuation differences between neutrons and gamma rays to allow the transformation of dose levels appropriate for $f_e = 3.0$ radiation fields to dose levels appropriate for an arbitrary $f_e = x$ radiation field. The following symbols are used in this paragraph:

D_3 = Total external dose in rad for $f_e = 3.0$ fields.

d_{3n}, d_{3g}, = Midhead neutron and gamma dose, respectively, in rad, to a man resulting from exposure to D_3.

H_3 = Total midhead dose in rem to a man resulting from exposure to D_3.

TF_{g3} = Gamma-ray transmission factor for $f_e = 3.0$ fields, i.e., $TF_{g3} = 0.69$.

D_x = Total external dose in rad for $f_e = x$ fields.

d_{xn}, d_{xg} = Midhead neutron and gamma dose, respectively, in rad to a man resulting from exposure to D_x.

H_x = Total midhead dose in rem to a man resulting from exposure to D_x.

TF_{gx} = Gamma-ray transmission factor for $f_e = x$ fields.

All other symbols are as previously defined.

The transformation function is defined such that $D_3 = \alpha D_x$. An additional assumption is now required: The radiation response of human beings performing identical tasks, exposed to different mixed neutron-gamma radiation fields but receiving the same biological equivalent midhead dose, is the same, i.e., $H_3 = H_x$. Substituting the relations for H_3 and H_x leads to:

$$d_{3n}RBE + d_{3g} = d_{xn}RBE + d_{xg} \qquad [\ 11\ ]$$

Applying equations [5], [6], and [7] gives the following results:

$$d_{3n} = .75\ TF_n D_3$$

$$d_{3g} = .25\ TF_{g3} D_3$$

$$d_{xn} = F_{xne} TF_n D_x$$

$$d_{xg} = F_{xge} TF_{gx} D_x$$

Substituting these results into equation [11] yields:

$$D_3(.75\ RBE\ TF_n + .25\ TF_g) = D_x(F_{xne}\ RBE\ TF_n + F_{xge}\ TF_{gx})$$

Substituting equations [1] and [2], rearranging, and simplifying the result lead to the expression:

$$D_3 = \left[\frac{x(0.51\ RBE + 0.05) + 0.54}{(1+x)\ (0.38\ RBE + 0.173)}\right] D_x,$$

and the quantity in brackets must be α by definition, thus:

$$\alpha = \frac{x(0.51\ RBE + 0.05) + 0.54}{(1+x)\ (0.38\ RBE + 0.173)} \qquad [\ 12\ ]$$

Note that for any value of RBE (or for the transmission factors too), when $x = 3$, $\alpha = 1$.

4. DETERMINATION OF CASUALTY DOSE LEVELS.

a. The PRCC assumed that the RBE = 1. This study assumes the same. If that assumption is applied to equation [5] with the recognition that in all cases $F_{ni} + F_{gi} = 1$, the equation reduces to simply $D_{1h} = D_{1m}$. Thus, the assumption that one rad of neutrons is as effective as one rad of gamma rays for degrading performance (i.e. RBE = 1) leads directly to the result that equal midhead doses of radiation in rads elicit the same degradation in performance for humans and monkeys. Recall that this is how the basic extrapolation assumption was stated in the PRCC.

b. As prescribed in paragraph 3c, the Casualty Response Summary Curves for both the demanding and undemanding tasks were prepared (figures E-4 and E-5). To enable direct comparison between the results of the procedure presented in this appendix and those of the PRCC, the midhead dose levels reflecting PCI (permanent complete ineffectiveness in 50% or more of the exposed population) by the PRCC stated times of interest have been determined and are listed in Table E-4.

Table E-4 Midhead Nuclear Radiation PCI Dose Levels for RBE = 1.0

Time to PCI	Undemanding Task	Demanding Task
15 mins	9,200	4,100
1 hr	8,900	4,000
4 hrs	8,600	3,500
8 hrs	6,900	3,500
24 hrs	3,200	3,200

All doses are equivalent midhead doses in rad to man (D_{1h}).

c. To convert the levels listed in Table E-4 to the appropriate free-in-air PCI dose levels, the midhead dose levels are simply multiplied by the factor 1.80, determined previously from equation [10]. The results are contained in Table E-5.

Table E-5 Free-in-Air Nuclear Radiation PCI Dose Levels for RBE = 1.0

Time to PCI	Undemanding Task	Demanding Task
15 mins	17,000	7,400
1 hr	16,000	7,200
4 hrs	15,000	6,300
8 hrs	12,000	6,300
24 hrs	5,800	5,800

All doses are free-in-air doses in rad for $f_e = 3.0$ fields.

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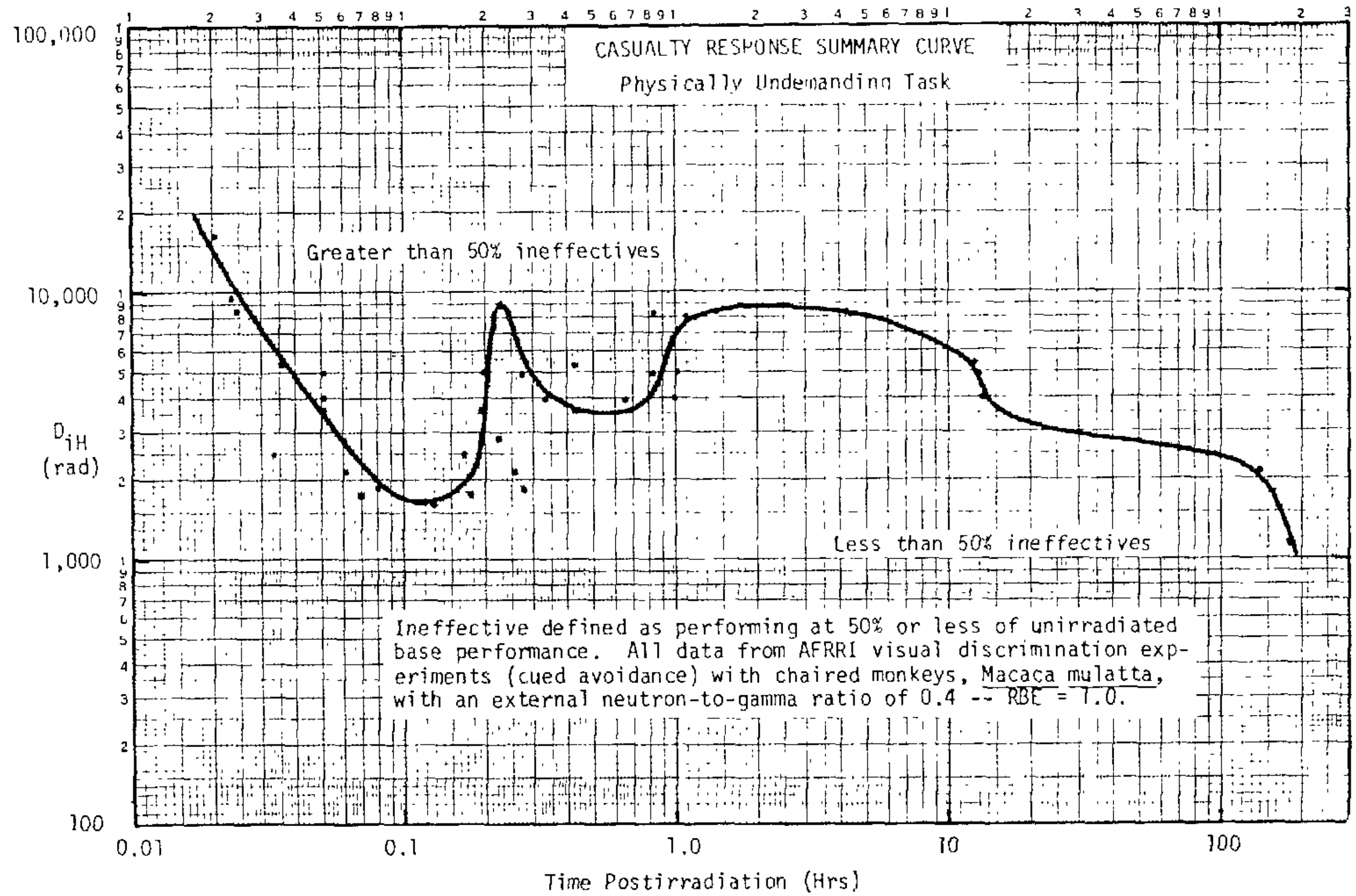

Figure E-4   Casualty Response Summary Curve
Physically Undemanding Task, RBE = 1

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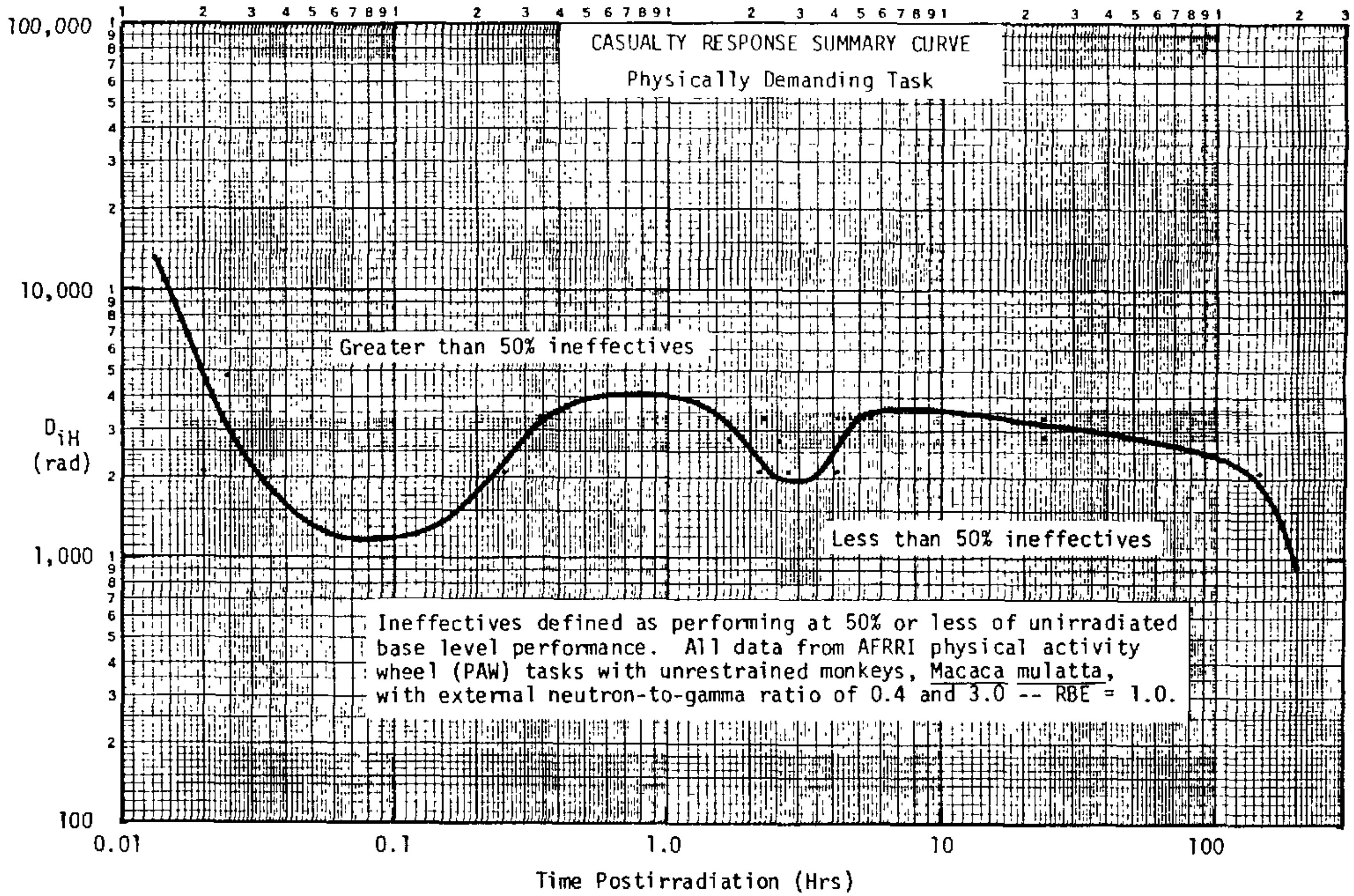

Figure E-5 Casualty Response Summary Curve
Physically Demanding Task, RBE = 1

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d. To complete the procedure, the transformation function α must be evaluated. This is accomplished by substituting RBE = 1.0 into equation [12] with the following result:

$$\alpha = \frac{1.01x + 0.97}{1+x}$$

A graph of the transformation function for RBE = 1.0 versus the incident neutron-to-gamma ratio is contained in figure E-6.

5. ALTERATION OF LEVELS DUE TO DIFFERENT RBE. The methodology presented in paragraph 3 was intentionally general. Many of the equations developed are functions of the RBE. Obviously, selecting different values for the neutron RBE culminates in different dose levels. Paragraph 4 determined casualty dose levels for the case where the RBE is assumed to be unity. That assumption, originally stated in the PRCC and continued in this addendum is not based on evidence that the RBE is, in fact, unity but rather, on lack of evidence indicating that the RBE has a value other than unity. The purpose of this paragraph is to demonstrate the generality of this appendix's methodology by illustrating the calculations for an RBE other than unity. So that the exercise not be strictly pedantic, an RBE of 0.3 was used because preliminary experimental evidence had suggested that such could be the case.

a. Assuming (for illustrative purposes) that the RBE is 0.3, equation [5] becomes:

$$D_{ih} = \frac{.3F_{nim} + F_{gim}}{.3F_{nih} + F_{gih}} D_{im}$$

The neutron and gamma fractions, being independent of RBE, are as calculated in paragraph 3b. Substituting their values into equation [5] leads to the two following results:

(1) Case I. $f_{em} = 0.4$. In this case, which corresponds to all AFRRI experiments using the visual discrimination task, equation [5] becomes:

$$D_{ih} = \frac{(.25)(.3) + .75}{(.69)(.3) + .31} D_{im} = 1.60\ D_{im}$$

Hence, a man in an $f_e = 3.0$ radiation field must receive 1.60 times the total midhead dose in rad received by monkeys exposed to an $f_e = 0.4$ radiation field to exhibit the same radiation response (with the assumption that RBE = 0.3).

(2) Case II. $f_{em} = 3.0$. In this case, which corresponds to most AFRRI experiments using the physical activity wheel task, equation [5] becomes:

$$D_{ih} = \frac{(.65)(.3) + .35}{(.69)(.3) + .31} D_{im} = 1.05\ D_{im}$$

Hence, a man in an $f_e = 3.0$ radiation field must receive 1.05 times the total midhead dose in rad received by monkeys exposed to the same $f_e = 3.0$ radiation field to exhibit the same radiation response (with the assumption that RBE = 0.3).

b. Casualty Response Summary Curves are now prepared for the demanding and undemanding tasks (figures E-7 and E-8). To show the alteration in dose levels caused by using RBE = 0.3, the midhead dose levels reflecting PCI by the PRCC stated times of interest have been determined and are listed in Table E-6. Continuing the illustration, the corresponding free-in-air PCI levels were determined from equation [10] and are reflected in Table E-7.

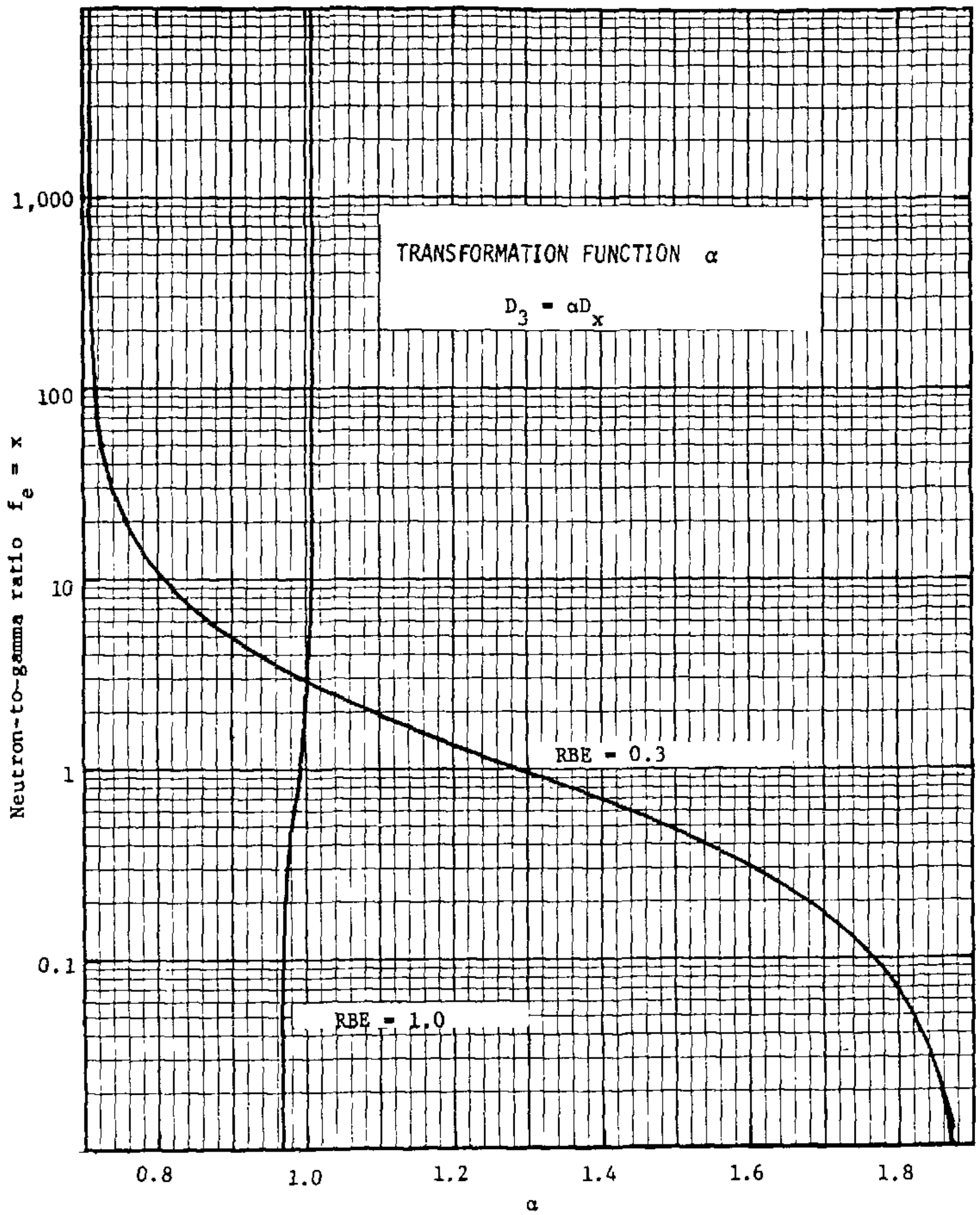

Figure E-6 Transformation Function

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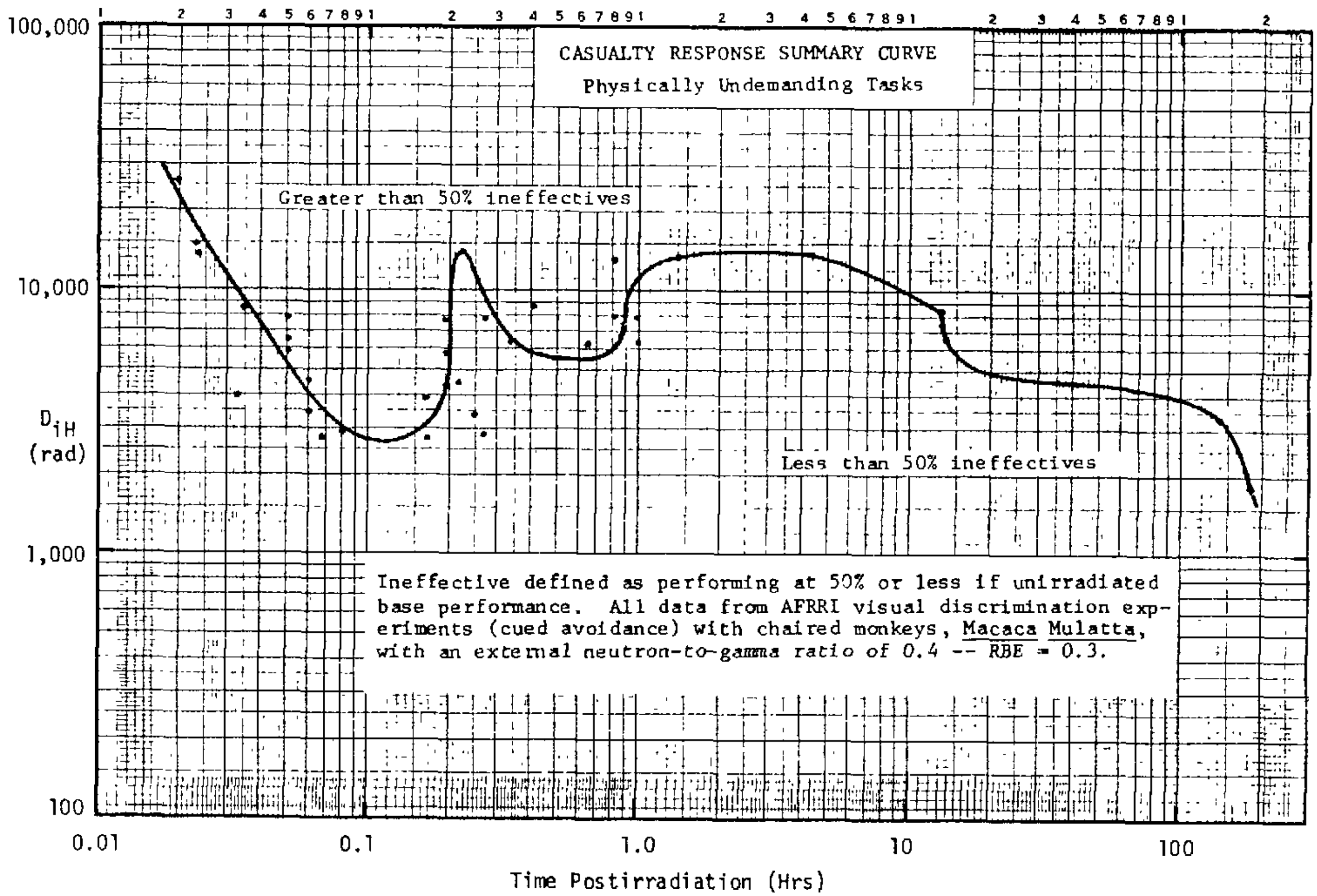

Figure E-7 Casualty Response Summary Curve
Physically Undemanding Task, RBE = 0.3

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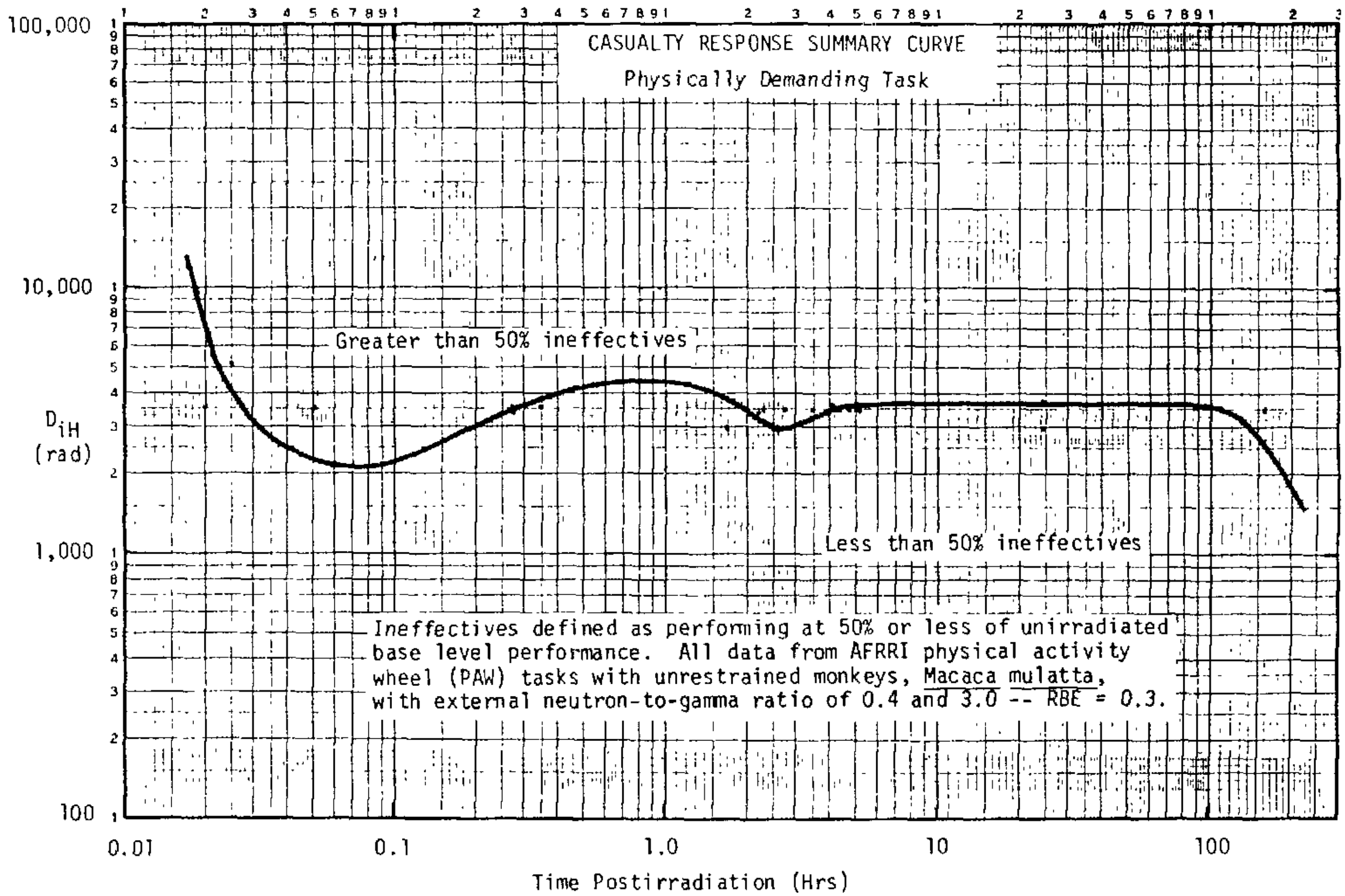

Figure E-8 Casualty Response Summary Curve
Physically Demanding Task, RBE = 0.3

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Table E-6 Midhead Nuclear Radiation PCI Dose Levels for RBE = 0.3

Time to PCI	Undemanding Task	Demanding Task
15 mins	15,000	4,500
1 hr	14,000	4,400
4 hrs	14,000	3,700
8 hrs	11,000	3,600
24 hrs	4,800	3,600

All doses are equivalent midhead doses in rad to man (D_{ih}).

Table E-7 Free-in-Air Nuclear Radiation PCI Dose Levels for RBE = 0.3

Time to PCI	Undemanding Task	Demanding Task
15 mins	27,000	8,100
1 hr	25,000	7,900
4 hrs	25,000	6,700
8 hrs	20,000	6,500
24 hrs	9,500	6,500

All doses are free-in-air doses in rad for f_e = 3.0 fields.

c. The final step is to evaluate the transformation function. Substituting RBE = 0.3 into equation [12] yields the following result.

$$\alpha = \frac{0.705x + 1.88}{1 + x}$$

This function has been graphed in figure E-6.

5. SUMMARY. The guiding principle for the procedure described in this appendix has been the scrupulous adherence to the base assumption, i.e., equate biological equivalent dose (rem) at the midhead position for identical response across the order of primates. For developing casualty dose levels, the incident radiation field is constrained to f_e = 3.0. Lastly, for applying those dose levels to different radiation fields, the transformation function α is used.

APPENDIX E REFERENCES

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E-2. AFRRI SR 74-29, Primate Physical Activity Following Exposure to a Single 2000-Rad Pulsed Dose of Mixed Gamma-Neutron Radiation, Armed Forces Radiobiology Research Institute, December 1974 (UNCLASSIFIED).

E-3. TM 1-74, The Calculation of Absorbed Dose and Tissue Transmission Factors, U.S. Army Nuclear Agency, Fort Bliss, Texas, 11 November 1974 (UNCLASSIFIED).

E-4. Letter, PSRP, Armed Forces Radiobiology Research Institute, 12 February 1973, Subject: Mid-Head Tissue-to-Air Ratios, Bethesda, Maryland (UNCLASSIFIED).

APPENDIX F. RADIATION DOSE LEVELS FOR ECHELONED FORCES

Examination of the ability of various nuclear weapons effects to blunt an armored attack has proven to be a complex, multi-dimensional task for the Working Group. Although some of the factors can be quantified and rigorously analyzed, others are necessarily vague and ill-defined. One important dimension which is difficult to evaluate is the distance beyond the FEBA* to a targetable military objective.

The intent of this appendix is to discuss the appropriateness of various radiation levels (free-in-air dose) as a function of this distance. To facilitate such a discussion, four regions are hypothesized. These regions are "target-oriented" in that they reflect how unit levels and missions of a highly mobile force, structured for echeloned deployment, might be configured in the preparation phase for a breakthrough operation. Many scenario-dependent factors (discussed in Appendix G) preclude precise region definitions; but such precision proves not to be essential.

The first region (Region I) is assumed to be the zone of employment for the first echelon regiment and extends from the FEBA to a depth of 15-30 km. Region II, occupied by the second echelon regiment, extends back to 40-50 km behind the FEBA. These two echelons constitute the first echelon division. The second echelon division occupies Region III which extends back to approximately 90-100 km, the total depth of the first echelon tank army. Region IV consists of the second echelon tank army and continues from 100 km back to about 200 km.

*Forward edge of the battle area.

Obviously, these region depths can be treated only as a "snapshot" of a very dynamic situation that is sensitive to geography, weather, time, and tactical operations. Once the breakthrough attempt begins, units in the rear assume various postures from assembly area occupation to movement toward and occupation of more forward positions. As the breakthrough develops, the second echelon division ultimately may be not much more than 20 km from the breakthrough sector, in final preparation for its exploitation role.

Current procedures and tactics do not really facilitate the attack of mobile targets more than a few kilometers (3-5) beyond the FEBA with Army nuclear weapons. Beyond these first few kilometers, nuclear targets have traditionally been fixed targets. Today's limited capabilities in target acquisition, intelligence data processing, weapon systems response times, and CEP are primary contributors to this targeting concept for anything other than air armed reconnaissance type missions. In such close proximity to the FEBA, rather high dose levels have been contemplated in conjunction with very immediate incapacitation of combatants.

Of considerable interest here is the potential utility of using lower radiation levels against targets in Regions II-IV. The idea of attacking mobile targets further back is not new, but, so far, the capability has been quite limited. Air delivery has many well known drawbacks for this role, such as enemy air defense, competing priorities, and the need for close coordination with ground units.

However, new capabilities are emerging that significantly increase the Army potential for engaging these more remote targets. Such potential exists at least for Regions II and III, and takes into account countermeasures, range intelligence and accuracy limitations. Surveillance and acquisition

techniques are beginning to reach tens of kilometers behind the FEBA. Near-real-time intelligence data processing can provide acquired target information to delivery systems, rapidly. Reductions in response time, i.e., target acquisition to weapon delivery, from hours in many cases to minutes means a substantial increase in the fraction of enemy combat units that are still in their detected locations for a sufficient time to allow engagement. For any given engagement, the faster the response time, the fewer the number of weapons required. Furthermore, accuracy is becoming range-independent and this, coupled with tailored effects and stand-off systems, allows an effective engagement of any target that is acquired and that can be reached in time. In other words, mobile targets are in some cases becoming "semi-fixed" as a function of target residence and target engagement times.

Clearly, any integration of this total "target engagement system" is difficult to achieve and to evaluate, but the potential impact is great. Being able to locate main and secondary attack units permits discriminate and timely allocations of firepower and limited reserves. A successful nuclear attack against the deeper echelons of enemy forces would inevitably have great influence on the subsequent battlefield capabilities of those decimated forces.

The optimism manifested thus far is intentional, so as to get the reader's heart and mind to follow new thoughts and applications. Appropriate radiation levels for targeting in these regions should be tentatively established now to facilitate studies of the impact of technological advances. There is a note of caution, however; to realize the full benefits of such applications, they must be accompanied by changes in operational concepts, procedures and tactics. This includes the adoption

of appropriate targeting techniques and radiation levels. Furthermore, reexamination of the factors important to such deeper tactical applications may lead to improvements in the performance of existing systems.

Having defined the regions for consideration and addressed the engagement capabilities, it is also important to understand the operational time-dependence associated with these regions of echeloned forces. There is no simple correlation such as a km/hr movement rate to determine when an echeloned element will arrive at the FEBA. Forward echelons must first initiate a breakthrough as a prelude to higher echelon movements.

If all goes well for the attack in Region I, those first echelon forces will succeed in their penetration of the defenses. It will then be a few hours (6-8) before the lead elements of the second echelon regiment (Region II) will be within 1 km of the FEBA, and it will take longer for all its elements to arrive. These forces must then attempt to rout the defender, and open the gap for the passage of the second echelon division. By the time the Region III forces reach the FEBA for exploitation and pursuit, at least half a day has passed. These times are measured from the beginning of the breakthrough attempts. The build-up of these forces to conduct this operation also takes a few hours. Thus, if the main attempt is identified and responded to with nuclear weapons during build-up or onset, exposed units will have had at least this much time prior to contact for delayed radiation effects. This time scale assessment is optimistic for the attacker; the misfortunes of war can easily increase these times-to-contact, and that half a day can easily grow up to a day or more before the second echelon division would be in the heat of battle. For Region IV forces, <u>at least</u> a day of time delay must be expected.

In this type of offensive doctrine, the effectiveness and timeliness of the second echelon divisions and succeeding echelons of forces are vital to sustaining the offensive. Hence, a defender's capability to degrade and perhaps stop this reinforcement may relieve pressure at the FEBA. Attacks on forces 20 km or more behind the FEBA also make such issues as troop safety easier to manage.

The target is generally a co-mingled complex of hard and soft, combat and support, elements; i.e., armor, artillery, command posts, missiles, air defense, and logistics. However, these forces must not simply "survive" an attack; they must efficiently prepare for and wage battle. It is in this context that a discussion of lower exposure doses and synergisms may prove meaningful.

For a 1 kT, standard fission, low air burst, the 500-3000 rad transition occurs with a range change of approximately 250 m covering an area of approximately 1 km^2. Hence, comparing what happens in a 500-1000 rad lower dose environment with what happens in a 3000 rad environment should help to illustrate the military significance of reliance on the lower dose criteria for attacks on higher echelon forces.

In the weapon effects description appendix (Appendix A), environments separated by a factor of ten in dose are described. The 500-3000 rad zone is encompassed in the 300-3000 rad range discussed there. In addition to the prompt nuclear radiation, there is a blast environment of 2-4 psi, a thermal environment from 2-8 cal/cm^2, and winds from 30-60 fps. The combination of these effects can be very disrupting at least. Exposed skin will suffer second degree burns, materials may be charred, trucks may be overturned, trees may be uprooted, debris and

glass will be flying about, and dust and smoke may persist for a prolonged period. Some of the troops, in addition to receiving radiation doses and thermal burns, will have been thrown about or may be suffering flashblindness. This is, in its totality, a very hostile environment, superimposed on the traditional rigors of war. A unit subjected to this treatment will stop and will have repairs to make, medical treatment will be required, and much reorganization and consolidation will be necessary before the unit can be ready for battle as a coordinated unit.

The near-simultaneous occurrence of these environments will make the impact of each specific environment more significant than if it occurred by itself; the degree of additional impact of these combined effects, however, is not yet adequately understood. Vehicles and weapon systems subjected to light and moderate damage blast levels are also subjected to the other environments discussed above. Hence, broken antennas, obscured firing sights, sheared wheels, ripped/warped doors and fenders, damage from secondary effects, etc., may be commonplace. Light damage is considered repairable with 0-1 manhours by organizational maintenance and moderate damage with 1-32 manhours by a field maintenance unit. For one vehicle in a test environment, this may be appropriate. On the other hand, if a large fraction of a unit suffers such damage, parts and available personnel may not be able to meet the demand. One or a few pieces of equipment can perhaps be made combat functional by healthy personnel with full logistical support. On the other hand, damage to many pieces of equipment over a large area at one time can easily overtax any maintenance and resupply system. Furthermore, the unit's personnel will be functionally impaired to varying degrees by

the nuclear radiation and this is the issue that may significantly impact upon the unit's attempt to return to combat readiness in a timely fashion.

The majority of the personnel exposed at a few hundred to a few thousand rads become and remain functionally impaired within an hour. A few hundred rads will produce severe nausea and vomiting that will occur intermittently, peaking in approximately eight hours and then declining in intensity over the next few hours to days. However, as these responses are declining, diarrhea and fever are increasing and may persist for days. In addition, those exposed may tire easily. More than half will die, with a precipitous decline in performance prior to death. Although able to perform simple tasks, they will be degraded in combat effectiveness; only the degree of significance is uncertain.

Data indicate that physical activity may be more severely affected by radiation than cognitive activity. This, coupled with increased "fatigability," may make it very difficult for a unit to restore its combat posture following subjection to the environment discussed earlier. In conventional conflict, a given percent of a unit's manpower may be casualties, just as a quantifiable amount of equipment is damaged. In this situation, essentially all personnel are casualties to some degree, perhaps most of the equipment is damaged to some degree, and, hence, the unit as a complex fighting system has an overall performance decrement that will disrupt, delay, and possibly prohibit its mission performance.

These units in Regions II-IV are not in battle with the adrenalin juices flowing. If in assembly areas, some are providing aerial and perimeter security; some are performing

maintenance or cleaning weapons; others may be feeding, resting, or making final plans and preparations. In other words, they are obviously in a more vulnerable posture than troops in or near contact. If on the move, they are likely to be less tactical and "unbuttoned" to allow more effective air and local security, more rapid movements, etc., particularly under the "cover" of darkness with the inherent difficulties of movement and control.

The stringent, highly disciplined posture required for near FEBA forces would be increasingly difficult to maintain in Regions II through IV. To be buttoned up or in shelters would restrict movement and inhibit preparatory activity, generally interfering with the attacker's ability to sustain the offensive. In other words, if the capability is developed to attack mobile forces in these higher echelon regions, it will seriously affect the attacker's tactics and procedures.

Although mobile armored forces have readily available protection to significantly reduce the effects of thermal and perhaps blast environments, if taken advantage of prior to the time of detonation, there is little that can be done to protect against the prompt radiation environment short of seeking shelter in underground bunkers. Protection factors of two or less are typical if mobility is retained. For this reason, the nuclear radiation exposure is more predictable than are the thermal or blast injuries, and is less sensitive to details of warning or shielding for military units actively involved in an attack.

If all of the points discussed in this paper are now integrated, the potential impact of low radiation levels on units in an operational context begins to emerge and take on more significance than when discussed as a separate mechanism to which a specific individual is subjected.

As an example, it can be at least half a day or more before the second echelon division (Region III) is in contact, even if all goes well. If units in Region III are attacked and subjected to the 500-3000 rad environment, except for the first few minutes, they will be functionally impaired for the entire time before contact. Hence, the radiation dose will have had ample time to weaken and stress the unit. An important point to add is that much of the unit would have experienced substantially higher doses; in an area that experiences at least 650 rad, roughly half of the area will be subjected to more than 3000 rad (from a low air burst 1 kT weapon).

That portion of the force that does receive 500-3000 rad will likely have to do much of the mechanical reparations and medical care itself. At least the first few minutes will be occupied with digesting and evaluating what has happened and in getting reoriented. The radiation dose effects will soon follow.

The unit's personnel will have to put out fires and repair what they can while attempting to continue their mission, remain alert and disciplined, while experiencing periods of vomiting, nausea, diarrhea, fever, etc. The degree of "fatigability" is unknown, but combat units and support units in any of these regions must perform a substantial amount of physical activity. The heavy exertion involved in loading ammo, performing field maintenance, repairing damage from blast and other effects, and aiding and treating casualties will exhaust many of the troops and further degrade their combat capability. Rest and recuperation are not compatible with the time-sensitive tasks and missions such units must face.

It is not clear just what fraction of unit performance degradation will occur, but casualties in the 500-3000 rad dose range will suffer effects, particularly in context with everything else discussed, of a magnitude and severity that will interfere with their effectiveness. Furthermore, it may not take much of a delay in an echelon's responsiveness or its performance capability to endanger the success of the entire breakthrough operation.

The mission disruption levels discussed may have more utility in these rear regions than near the FEBA. There are clearly many judgmental and qualitative statements made in this discussion, and a more rigorous treatment of this concept may be in order. At the same time, there are many inconsistencies in the available data, and it is not yet clear as to what specific data are needed, how it can be obtained, or how sensitive it will be to battlefield uncertainties.

Improvements in targeting capabilities, as discussed earlier, should make the engagement of these deeper mobile targets more practical, and the suggested lower dose levels for military effectiveness should enhance the perceived effectiveness of such applications. Lower required dose levels will help offset target location error (TLE), or if TLE is compatible with weapon accuracy, may allow a lower yield or fewer weapons for a given engagement. All of these considerations could be helpful in a commander's targeting and delivery decisions.

The pursual and refinement of this concept may require a better understanding of the combined totality of effects produced by a nuclear weapon, the performance degradation as a function of time of a unit subjected to these combined effects, and the resulting impact on the unit's mission performance.

The broad implication that emerges from this discussion is that low yield nuclear weapon environments are more effective than current doctrine indicates, and lower levels of radiation doses (500-3000 rad) may have tactical utility for deeper mobile targets (15-200 km from the FEBA) where time, distance, and operational requirements may contribute to mission failure for the attacked units.

APPENDIX G. OPERATIONAL CONSIDERATIONS, POLICY AND PLANNING

The operational considerations discussed here concentrate on Warsaw Pact forces in attack against NATO defenses, and the impact of nuclear weapons on such engagements.

SCENARIOS

Scenarios dealing with this hypothesized conflict have led to the strategy and tactics employed by both Warsaw Pact and NATO forces. The disposition and employment of troops and weapons dictated by these tactics will determine the potential effectiveness of nuclear weapons, and have influenced the selection of casualty and damage criteria.

Until quite recently, the scenario which has been adopted for NATO nuclear planning has been based on the following premises:

(1) The Pact attack is preceded by substantial periods of mobilization on both sides--roughly four weeks for the Pact and three weeks for NATO.

(2) The Pact attack, when it does come, will be restricted to conventional ordnance, the objective being to defeat NATO without recourse to nuclear weapons, if possible.

(3) If nuclear weapons are used in the conflict, first use will be by NATO.

In this scenario framework, NATO's use of TNW most likely will come at a time when Pact forces threaten to break through NATO general defense positions or have already initiated a breakthrough. Moreover, in terms of present NATO policy for TNW,

such use will probably be restricted to the battlefield area; the major purpose being to temporarily blunt the Pact attack, at the same time "sending a message" that a renewal of the Pact offensive carries the danger of nuclear escalation to general war.

Without commenting on the efficacy of this scenario, we point out that for incapacitating Pact armored force personnel with nuclear weapons, the time scale would be quite lengthy. Implied in this assessment is the likelihood of extensive Pact massing of forces for a breakthrough operation involving many hours and perhaps more than a day. It is during this massing that the Pact would present NATO with lucrative nuclear targets. Were TNW employed during such staging periods, the time for crew incapacitation would be much longer than were those same Pact forces already in assault and engaged with NATO defenses. Troops suffering transient incapacitation followed by a partial or total recovery period would only complicate the continued build-up for an impending armored thrust.

To carry out such a strike against Pact forces prior to attack presumes fast and accurate target acquisition information and prompt authorization to release nuclear weapons, assumptions currently with little credibility.

Beginning in 1975, the Secretary of Defense has issued a different picture of the Warsaw Pact Doctrine for war with NATO--a picture which strongly suggests a much different scenario for NATO-WP conflict. As enunciated in this year's (FY 1977) Defense Report, the WP is perceived to hold to a pronounced tactical nuclear doctrine. In addition, the possibility that the Pact attack on NATO may not entail a lengthy mobilization period is now given serious consideration. This Pact doctrine

may be summarized by the following statements extracted from the FY 1977 DOD report:

> The Forces needed to fulfill this role can best be understood by considering the two main cases that concern us in Central Europe: an attack which occurs after little or no warning or an attack that occurs after a large-scale Pact mobilization and deployment.
>
> . . . Almost one-half the Soviet total of front-line divisions are deployed in Poland, East Germany and Czechoslovakia. Together with non-Soviet Polish, East German and Czech divisions, they can probably march on as little as a few hours notice.
>
> . . . (The Soviets would like) to win widespread conventional warfare in Europe without necessarily resorting to the use of theater nuclear weapons.
>
> Even as the Soviets have improved their conventional capability . . . their forces, doctrine and strategy remain fully capable of combined conventional and nuclear operations . . . their TNF's (theater nuclear forces) appear to remain an integral part of their warfighting capabilities.
>
> Warsaw Pact forces are postured primarily for the type of theater-wide nuclear strikes pictured in their doctrine and exercises . . .
>
> Doctrine and exercises indicate that the Warsaw Pact places high value on tactical surprise with nuclear weapons. Their doctrine states that if the Warsaw Pact believes NATO is about to launch a major nuclear attack, it will seek to preempt with nuclear strikes on military targets. (Moreover, there are clear indications that the Pact fully appreciates the initial advantage to be gained by a first use of theater nuclear forces in the absence of NATO indications to use nuclear weapons.)
>
> Warsaw Pact armored forces and their immediate support (artillery, tactical air, SAM's) are postured and trained to exploit nuclear attacks by rapid, deep, multiple thrusts to destroy remaining NATO forces and seize NATO territory. These armored forces are equipped for operations in a nuclear and chemical environment, so as to maintain movement and keep constant pressure on NATO forces.

These observations seem to suggest the distinct possibility of the following scenario:

(1) A Warsaw Pact conventional attack with little or no warning and with the objective of defeating NATO without nuclear weapons being used by either side.

(2) If the WP advance into Western Europe meets with unexpected resistance, or Pact commanders perceive that NATO is planning to initiate TNW use, the Pact may conduct a surprise or preemptive nuclear attack against NATO forces.

(3) With the requirement "to maintain movement and keep constant pressure on NATO forces," it may be that the Soviet "blitzkrieg" doctrine will prevail and WP armored forces will seek to advance at a maximum rate.

In this second scenario, where the WP will enjoy the advantages of first nuclear use, NATO use of TNW most likely would involve targeting against forces advancing at a high rate of speed; in contrast to the first scenario where the WP requirement for massing would present large lucrative targets over a considerable time span. Under these circumstances (the WP already having used nuclear weapons, probably massively), NATO TNW use would be more directly to destroy an imminent danger--to defeat, not to just ward off an enemy force or to simply thwart WP objectives; the escalatory risk already having been taken by the WP. In this scenario, the time (after exposure) until the onset of incapacitation might have to be relatively brief, if WP armor is, indeed, advancing rapidly to exploit their nuclear

strikes. But, in view of the necessity for WP armor to maintain forward momentum, the period of incapacitation may not have to be very long.*

The effectiveness of battlefield nuclear weapons and their relationship to casualty criteria is a sensitive function of the scenario considered. It has to do with the doctrine of both sides; who uses nuclear weapons first and for what purpose. It poses questions regarding the nature of the battlefield situation at the time U.S. nuclear weapons are used: Are enemy armor units moving rapidly toward U.S. defensive positions? Or are they in a relatively static preparation phase? Does the U.S. plan to exploit the effects of its nuclear attacks (as the Soviet doctrine calls for) or does it intend to bank solely on the effectiveness of these attacks? And so on.

Obviously, there is no way in advance of actual conflict to determine what employment situations may exist and what decisions will be made regarding dosage criteria. However, in examining the possible nature of NATO/Warsaw Pact conflict scenarios, the Group's judgment is that, toward blunting Pact armored attacks the requirement for immediate permanent incapacitation (IP) would under most circumstances be too stringent.

TARGETING FACTORS

For either scenario, if the objective is to blunt or defeat Pact armor and its support, the more important target elements relevant to personnel incapacitation would be essentially the

*"Loss of speed in an attack or halting of a tank under direct enemy fire is tantamount to its destruction . . .," Antitank Warfare, Major General G. Biryukov and Colonel G. Melnikov.

same--i.e., tanks, APC's, artillery, air and missile support, antiaircraft, and logistics. With respect to determining nuclear incapacitation of these kinds of units, there are several important associated factors:

(1) Synergistic Biological Effects

The extent to which blast and thermal effects will enhance the effectiveness of prompt nuclear radiation in causing casualties depends upon the type of warhead, its yield, and the degree of protection for attacked personnel. For example, for 10 kT (fission) at distances corresponding to a dosage of several thousand rads, overpressures in the range of 5 - 10 psi will exist. Also, at this distance, thermal levels of 20-40 cal/cm^2 will exist. Exposure to such blast and thermal loads will cause casualties and significant damage, which, when combined with the high nuclear radiation doses, must add to the number incapacitated. How these corollary effects might affect the dosage criteria is not now sufficiently understood; but an appreciable reduction could result. On the other hand, troops attacking in tanks and APC's are afforded considerable sheltering from thermal radiation, and some protection from blast and ejecta, and are partially shielded from nuclear radiation. With maximum assault protection, blast and thermal effects may contribute less to incapacitation than the radiation effects, and higher doses may be required, even with synergisms between injuries.

For fission warheads in the kiloton range, at distances (from ground zero) where prompt casualty-producing nuclear radiation intensities exist (i.e., 1000 rads or greater), blast overpressures of several psi and thermal intensities of several calories/cm^2 can also exist. The simultaneous occurrence of all of these hazards makes it particularly difficult to predict troop casualties; these combined effects may lower the levels at which injury may be expected. Added to this possibility is the general physical chaos, resulting from such blast and thermal intensities, i.e., dust, fires, smoke, flying debris, etc. There is little hope of accurately anticipating the levels of injury and impediment that might result from these direct and secondary effects, but, in the Working Group's judgment, these factors will play a role in enhancing the biological effectiveness of the nuclear radiation.

(2) Synergistic Physical Effects

Dosage criteria, for various levels of performance decrement, have been predicated on the assumption that the specific military task at hand will remain the same after irradiation has occurred. For example, the resulting performance decrement for, say, a tank crew exposed to some radiation level carries the premise that the tank and its associated equipment is not significantly affected by the blast, thermal, or nuclear radiation. Depending upon the nature and the yield of the nuclear weapon used, this simplifying assumption may not be credible. It is more prudent to consider the performance decrement both due

to effects on the crew and on the weapons systems and equipment--i.e., attempt to determine the physical-biological synergistic relationship.

There are indications that the Soviet Army has few procedures for providing battlefield repair and replacement, and Soviet armor personnel may expect to deal with damaged equipment themselves. For such situations, personnel incapacitation criteria may more immediately apply to a necessary repair function, and certain repairs may be more physically demanding than the operation of the vehicle itself. Or, if certain repairs are not readily in order, the operating of damaged weapons and equipment may become a more difficult or impossible task when combined with diminished capabilities due to nuclear radiation.

To illustrate this point, if fission weapons having yields on the order of 10 kT are used, slight damage to tracked vehicles and self-propelled artillery and moderate damage to wheeled vehicles occurs at about the 1000 rad distance. These coincidences of damaged equipment and relevant dosages (dosages which will produce certain death as well as radiation sickness symptoms) raise the question as to how much the level of physical damage may enhance the biological effectiveness of a given dosage level. This question currently has no answer; but the matter seems important and should be addressed.

The accompanying blast and thermal phenomena can cause significant damage to military vehicles and equipments, making their use after nuclear attack

more difficult; perhaps necessitating repair. Physical exertion thus required can exacerbate the radiation effects on troops. In addition, the widespread physical chaos in the attacked area will make the operation of equipment more difficult than before the nuclear burst. These damaging and disruptive effects, will, in the Working Group's judgment, constitute a meaningful enhancement of the radiobiological effectiveness of the burst, working to further reduce dosage requirements to produce a given performance decrement.

(3) Immediacy and Duration of Effects

The necessary immediacy of incapacitation or degraded performance is very dependent on the conflict scenario. For a conventional war which turns nuclear through NATO action, WP tactics may involve lengthy massing periods prior to breakthrough attempts. On the other hand, if the WP uses TNW first to ensure the continuity of the momentum of its blitzkrieg attack and NATO then responds, but in a weakened defensive position, there might be a substantially more stringent requirement for more immediate effects and, therefore, a higher required dosage for an attack on first echelon WP units. On the other hand, if the defense is dispersed in depth so that the attacking forces must sustain their attack for more than an hour in order to penetrate, the time factor may prove less critical. The required duration of effects relates directly to the nature of the conflict.

Going further along these scenario lines, one can postulate a situation where, over a period of time--i.e., days--NATO's defenses (conventional and nuclear) succeed in thwarting the Pact offensive to a degree where the war seems likely to last weeks or even months; the assumption being that both sides choose to keep the war limited to the theater rather than escalating to general nuclear war. For this set of circumstances, dosages below the ETI* level could emerge as very significant when, over a number of days following exposure, delayed casualties continue to develop.

The choice of scenario and the meaning of dosage criteria are very sensitively related. The present criteria are considered in the narrow framework of level-of-effects and the onset and duration of human response. If considered macroscopically in the over-all context of the struggle, the assessment of radiation dose criteria can be of a very much different nature. However, as one moves, seemingly more realistically, from clinical descriptions of individual dosage responses to complex battle consequences, the problem becomes increasingly less amenable to quantitative analysis and merges more into the realm of broad judgments.

(4) Collateral Damage Constraints

"Acceptable levels of collateral damage," resulting from TNW employment, in the real political world,

have only recently found agreed-upon definition. Moreover, it is most difficult to assign relative weights to levels of civilian casualties and urban physical damage. Even if such comparative values could be agreed upon, there is no sure way of predicting civilian dispositions during the war. Therefore, how vulnerable they may be to nuclear weapons effects will usually be quite uncertain.

As a consequence of these above-mentioned intangibles, the problem of collateral damage has been addressed in terms of *constraints determined* by the *requirement* to keep certain intensities of weapon effects away from the periphery of areas having peacetime civilian populations of a given size or larger. However, as of now, there has been no common agreement in NATO on the minimum civilian community population that may be placed at risk.

How realistic this "constraints" approach may be is extremely difficult to assess. Whereas it might limit the amount of collateral damage which NATO's TNW may produce, it does not help in the acquisition or targeting of WP forces. In fact, some have argued that should NATO stringently adhere to such a constraints practice, WP forces may deliberately employ "city-hugging" tactics in an attempt to reduce NATO's TNW strike potential. Furthermore, in nuclear conflict, WP forces may disperse significantly beyond normal conventional concentrations--thereby driving

up required NATO TNW yields, and further exacerbating the collateral damage constraints issue.*

DOD, over the last year, has been increasingly insistent on the need to reduce the collateral damage potential inherent in the TNW stockpile. Former Defense Secretary Schlesinger, in his "Theater Nuclear Force Posture in Europe" report of 1975, stressed the military value of reducing collateral damage: ". . . reduction of collateral damage should make it more credible to the WP that the Alliance will use nuclear weapons. . . . Recent studies indicate that collateral damage could be further reduced, with acceptable reduction in military effects by changing tactical procedures now in use for selecting weapon-target combinations, and utilizing to a greater extent the current low-yield weapons."

Defense Secretary Rumsfeld, in his FY 1977 Annual DOD Report, supported these statements: "These goals (for improving TNW capabilities) are also furthered by . . . exercising control over collateral damage to enhance the credibility of our TNF deterrent posture and reduce undesired damage should deterrence fail."

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*With the acceptance of nuclear weapons into the arsenals of armies, a tendency is clearly observed for expansion of the zones of advance. . . It is impossible to determine the width of an attack front purely arithmetically, without consideration of the concrete conditions of the situation. The size of the attack front depends not only on the composition of friendly forces, the nature of the defense, and density of enemy troops and material, but also on the other factors and, above all, on the use of nuclear weapons . . .", The Offensive, Colonel A. A. Sidorenko, Moscow, 1970.

If one were to hypothesize that in an actual NATO/WP war a constraints-based TNW employment practice (reinforced by the above-mentioned DOD admonitions) dominated NATO's use of nuclear weapons, circumstances could arise in which: (1) required yields could not be used; (2) or a significant reduction in military effectiveness resulted from the necessity to employ lower yields than needed; or (3) no TNW could be used at all because a lower, acceptable yield was not immediately available in the sector where TNW were needed. On this basis, to reduce the possible extent of such curtailments in TNW effectiveness, the military effects dosage criteria might be viewed somewhat less narrowly and stringently. Rather than determine dosage requirements (and thus yield requirements) on the necessity to degrade the effectiveness of a WP unit by a given amount within a given period of time, the judgment might involve trying to balance the military risks arising from selection of lower dosage criteria with possible lower military effectiveness against the risks of increasing collateral damage.

(5) Training, Morale, Esprit de Corps, etc.

Warsaw Pact forces (Soviet forces in particular) are trained and indoctrinated to emphasize patriotic dedication in combat. On the other hand, to a far greater extent than in NATO, the special dangers from nuclear bursts are emphasized, with very special attention being given to nuclear radiation and its associated psychological and morale effects. In this connection, we have the following kinds of statements:

> In modern war, numerous factors will influence the feelings and mental state of the soldiers and commanders. Above all, the personnel will be under the influence of high combat spirit and a profound awareness of the necessity to quickly and successfully carry out the combat missions. At the same time, under a situation of the use of nuclear weapons, we must not exclude the possibility of temporary shock and the appearance of feelings of fear and uncertainty... On Guard for Peace and the Building of Communism, Soviet Defense Minister, A. A. Grechko, 1971.

> In determining the effects of nuclear weapons on the nature of the offensive, consideration should be given not only to the material damage inflicted directly by it, but it is also mandatory to consider the tremendous morale and psychological effect on the personnel... The soldiers who have survived the nuclear strikes... will constantly think about the dangers of radioactive irradiation. This unseen danger of irradiation and ignorance may cause a sense of alarm, fear, and excited state and passivity in actions which will lead to reduction in the combat qualities and activity of the personnel. The Offensive.

For the obvious reasons, it has not been possible to quantify the morale factor associated with nuclear radiation exposure. On the other hand, the Soviets appear to regard this problem quite seriously and, toward a determination of our incapacitation criteria, their assessment of this factor would seem to count most.

(6) Nuclear Effects Areas and Military Target Size

In attempting to determine the effect of conventional bombardment--e.g., artillery--of a military unit, the effectiveness of an attack has to take additional

factors into account other than the amount of ordnance delivered. These additional factors include probable protection; the inhomogeneity of effects over the target area (i.e., casualties and non-casualties can exist in sectors quite small compared to the overall target area); and the fact that target damage and casualties may accrue over a considerable period of time.

For radiation from nuclear bursts used against armored units and their support elements, however, the obverse is the case. Protection factors are sufficiently small as to make armored personnel comparably as vulnerable as exposed troops. While in the conventional weapons case, separations of a few meters can be the difference between no injury and death, the homogeneousness of nuclear radiation over many tens of meters distances (small compared with a neutron "mean-free-path" which can be more than 200 meters) ensures that uniform exposure and therefore similar casualties will exist over large areas.

Finally, for the nuclear attack, all the casualties are inflicted in a small fraction of a second, whereas an artillery barrage often takes a half to several hours to cause comparable casualties.

These key differences in conventional and nuclear effects suggest that the unit or team performance degradation resulting from nuclear effects (at a given casualty level) may be more serious than from conventional ordnance attacks.

The onset of incapacitating symptoms (whether transient or permanent) would produce the realization that no real protection existed. The fact that over the area of significant effects essentially <u>everyone</u> is affected (and knows it) does not lend to the "invulnerability" syndrome of conventional warfare ("It didn't happen to me, so it won't happen to me.").

In contrast to the scaling laws for blast and thermal effects, the intensity of initial nuclear radiation drops off quite sharply with distance. Roughly speaking, at radii of several hundred meters or more from ground zero, a change in distance of 100 meters implies a two-fold change in dosage. Thus, at a kilometer from about 5 kT, a dosage of 1000 rads exists, while a few hundred meters closer in, the dosage is on the order of 10,000 rads or greater. Since the dimensions of combat companies or battalions are larger than a few hundred meters, it is fallacious to judge the coverage and response of an entire combat unit on the basis of a single dosage level; rather, a highly inhomogeneous situation will exist over the unit area with much of this area probably covered by far larger dosages.

(7) <u>Unit Vulnerability versus Individual Response</u>

Since we are concerned primarily with a "team" response, as contrasted to determining weapon effectiveness on an individual, it is not realistic to assess the effects at a single dosage level--such as 1000 rads, when significant parts of the unit receive far higher dosages.

As an example, consider a tank battalion exposed to a kiloton burst. There may well be a performance decrement in those tank crews exposed to relatively low dosages, a decrement significantly in excess of that due to radiation effects on that crew alone. When supporting fire from any more heavily exposed tanks in the battalion is lost and the command elements (more likely to be in the higher dosage area) can no longer function effectively, each tank runs greater risk of being destroyed by enemy conventional firepower.

Within such a field of interest as a tank company, all of the personnel would be irradiated. The radiation dose and the individual response to that dose would vary, but if the unit were hit, nearly all troops would receive doses above hundreds of rad, producing significant effects in most of them. It is also known that there is significant degradation in irradiated individuals who are not incapacitated. Further, not all types of performance are affected equally by radiation--e.g., it appears that physical motor activity is more affected than cognitive performance. From these facts, it can be inferred that the effect of radiation on unit efficiency would be greater than that derived from adding up all the individual incapacitations.

Significant degradation in unit effectiveness may be projected from many relatively individual degradations. The evaluation of such decrements in light of the interactive organization of combat units poses a highly complex problem which needs investigation.

The approach to defining this problem involves operational and task analysis, laboratory identification of radiosensitive and radioresistant tasks and subtask elements, parameterizing crucial tasks for radiation effects and the application of these results to the tactical theater using a refined mission success model.

While it is not possible to quantify the impact of these two factors--inhomogeneity of effects and the interdependency of a combat unit--the intuition here is that some lower dosages may have more military relevance than is suggested by individual response predictions.

(8) The Role of Shelter

The difference in nuclear vulnerability of troops in the open and troops in shelter is striking. A well-prepared field fortification may protect men from injury or incapacitating doses at ground zero from an air burst, while a standing man can become a casualty as much as a kilometer away from a 1 kT burst. When combatants face nuclear attack, they may learn quickly what constitutes adequate shelter, and adapt their tactics to take advantage of existing shelter.

CURRENT CRITERIA

Current radiation exposure criteria deal with levels of performance degradation as a function of the expected military task (i.e., physically demanding or undemanding) and the time

after exposure. Considering the basic limitations affecting the extremely difficult problem of translating animal data into expected human responses, the Working Group feels that the procedures followed in deriving the criteria most recently set forth by the Army Nuclear Agency (Appendix E) are reasonable. However, the criteria are limited to estimates of individual human responses, and do not reflect directly the consequent impact on military combat units. Furthermore, three out of four levels quoted deal with immediate incapacitation, with seemingly less than adequate attention to the consequences of other lesser reactions to radiation exposure. In addition, the Army/JCS criteria do not consider any synergisms between other injuries or weapon effects, which can result in comparable incapacitation or degradation at lower doses.

For these reasons, the Working Group does not believe that the present criteria represent the best possible estimates for either weapon employment or warhead design requirements.

POLICY AND PLANNING

There are four major areas of concern regarding U.S. tactical nuclear weapons where dosage criteria are of importance:

- Employment in conflict
- Policy and planning
- Analytical studies
- New warhead design

The employment of battlefield nuclear weapons cannot be predicted accurately in advance. The decision for the release of a given weapon will involve a number of factors--military

and political--whose importance will be strictly a function of the exigency at hand. And almost certainly those factors which are amenable to some degree of analysis in peacetime will be distorted by the emotions of wartime. Nevertheless, it is important that those who may participate in such decisions should be made aware of the limitations and deficiencies of the dosage criteria with which they are working so that their judgment can be exercised with a greater appreciation of the operational aspects of the problem.

U.S. policy and planning for TNW employment bears a direct and critical relationship to the problem of battlefield casualty criteria. The past dependence on blast effects has been a major factor in the political considerations of TNW. Even with the acceptance by the U.S. military of initial nuclear radiation as a legitimate and effective kill mechanism, there has been a tendency to regard dosage requirements in a conservative fashion, thereby keeping warhead yield requirements on the high side. This conservative approach has reflected importantly on the credibility of U.S. policy and planning for TNW. A lessening of the stringency regarding casualty criteria would work in the direction of improving credibility, and in so doing, enhance the widely-held destructive image of TNW.

Analyses of tactical nuclear warfare depend importantly on the assumed casualty criteria for the employment of battlefield nuclear weapons. In this respect, it is noted that to date in these studies, that there has been a wide variation in the assumed incapacitating dosage levels, and essentially no attempt by the analysts to determine for themselves either the meaning of incapacitation (in an operational sense) or the reasons for the selected dosages. Since these studies have been, and are being, conducted to shed light on TNW problems,

- Tactical units (i.e., armor and artillery) having dimensions of several hundred meters, or greater, which are exposed to at least 3000 rads (free-in-air dosage) in combination with other nuclear effects from weapons in the kiloton range will suffer such extensive operational degradation as to be rendered ineffective on the nuclear battlefield almost immediately after exposure. Even for exposures of at least 1000 rads, very serious operational degradation will result.

- At levels of at least several hundred rads, such units which are not immediately engaged in combat but which could be committed within several hours will be sufficiently degraded in potential performance that their actual employment at this later time may be precluded.

APPENDIX H. SOVIET GROUND FORCE OPERATIONS IN A NUCLEAR ENVIRONMENT

1. GENERAL

The data used here has been extracted from open source documents, both domestic and foreign. The following operational procedures are Soviet nuclear weapons employment concepts and tactical defensive measures when operating either in an active nuclear environment, or under the threat of an active nuclear environment. As such, they must be taken into consideration when looking at Soviet Armored units as prospective targets for US nuclear weapons.

1.1 Nuclear Weapons Employment Concepts

- Nuclear, chemical and/or conventional fires are employed with surprise to increase their shock effect.
- An initial massive nuclear (and/or chemical) strike in great depth is viewed by the Soviets as a means to gain surprise, achieve a major penetration, and destroy effective resistance.
- Tactical use of nuclear weapons within the zone of responsibility of the division or higher command is possible with the launchers organic to those levels.
- The pre-planning of a massive nuclear and/or chemical strike--as an initiative or response--would be done at Front and Army headquarters.
- Most nuclear weapons would be airburst.
- Provision is made at all levels for firing nuclear and conventional weapons at targets of opportunity, but all fires are coordinated with the scheme of maneuver.
- The following is a list of potential targets the Soviets might engage with nuclear weapons:

(a) Tactical nuclear delivery systems, and their control means (high priority targets).

(b) Command posts, communications centers, radio and radar sites, and nuclear weapons storage areas (high priority targets).

(c) Maneuver elements, their reserves, and fire support.

(d) Known defensive positions, logistic facilities, and bridges.

- Extra care in warning Soviet troops prior to detonation of nuclear weapons at night is emphasized because of the greater hazard of temporary blindness from sudden bright light.

- Nuclear fires are integrated into conventional preparatory fires.

1.2 Defensive Measures

- Tanks will occupy the predominant position on the field of battle in an active nuclear environment because the armor of modern tanks provides significant shielding from radiation.

- Careful preparatory checks of vehicular and shelter seals are conducted to ensure they are as tight as possible. Special attention will be paid to food containers to avoid consumption of contaminated food or water.

- Personnel should be psychologically prepared for the use of mass destruction weapons. External effects simulators will be used in training.

- The destructive effect of the shock wave is affected to a considerable extent by relief and vegetation of the terrain.

- Parapet trenches provide protection from radiation.

- Terrain contaminated by radiation is crossed in closed vehicles at maximum speed.

- Except in extreme cases, dirt roads will not be used.
- Individual protective items will be worn at all times.
- Soldiers on foot will not sit or lie down unless the combat situation requires it.
- Personal hygiene and decontamination will be emphasized at all echelons.
- In order to avoid presenting lucrative targets for nuclear weapons, speed is emphasized in overcoming natural and manmade obstacles.
- Maximum use is made of dispersion to preclude destruction of large concentrations by a single nuclear blast.
- Camouflage, deception and concealment measures are emphasized.
- NBC reconnaissance and decontamination teams or units are provided to all combat organizations.
- The maximum number of rads a unit may be exposed to for a particular operation is announced by Front for each operation. Subordinate units may modify the guidance to a lower risk, but may not increase the exposure without prior approval.

2. ORGANIZATION

2.1 Front

Front is the largest ground force field command. It is both a tactical and administrative organization; its size is dependent upon mission and area of operation. A typical Front could be comprised of three combined arms armies, one tank army, one air army, one airborne division, and one artillery division.

2.2 Army

Soviet ground forces utilize two types of armies, combined arms and tank. The predominant combined arms army usually consists of three motorized rifle divisions and one tank division, while the tank army usually consists of three tank divisions and one motorized rifle division. Actual composition of the army varies with mission and area of operation (see Figure 1).

2.3 Division

Tank and motorized rifle divisions constitute the bulk of Soviet ground forces. There are also airborne and artillery divisions, both of which are normally Front assets (see Figure 2).

2.4 Tank Regiment

The tank regiment contains three tank battalions with a total of approximately 90 - 95 medium tanks. Although the tank regiment has no organic motorized rifle personnel, it usually receives a motorized rifle battalion from the motorized rifle regiment in a tank division. The tank regimental headquarters is identical to the motorized rifle regimental headquarters and includes a limited staff and support for the commander. Approximately 28 officers and 32 enlisted men are assigned to a regimental headquarters. It functions both as a tactical and administrative headquarters. Two tanks are included in the headquarters. A tank regiment deployed in an advance to contact is shown in Figure 3.

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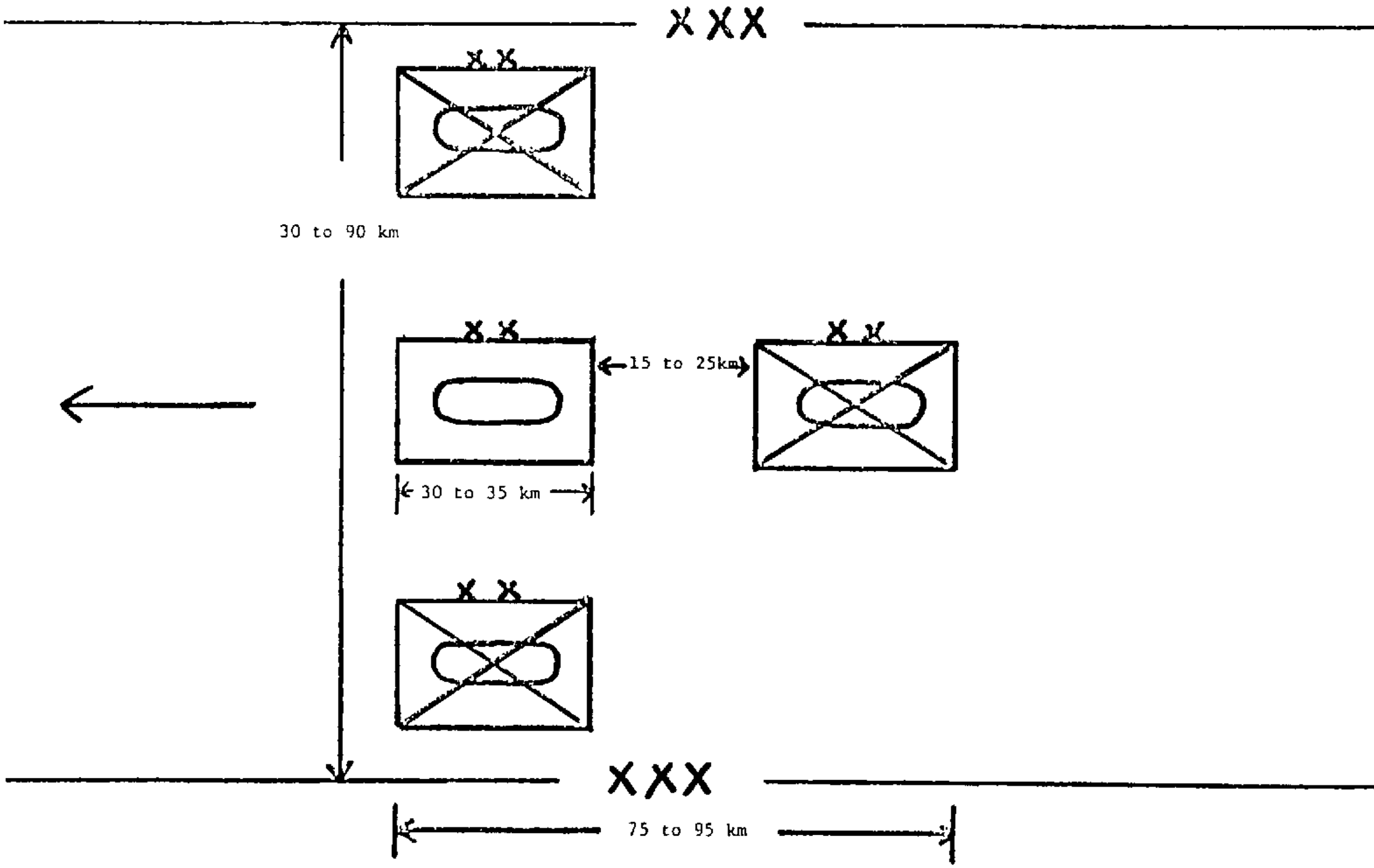

FIGURE 1. COMBINED ARMS ARMY IN FRONT FIRST ECHELON

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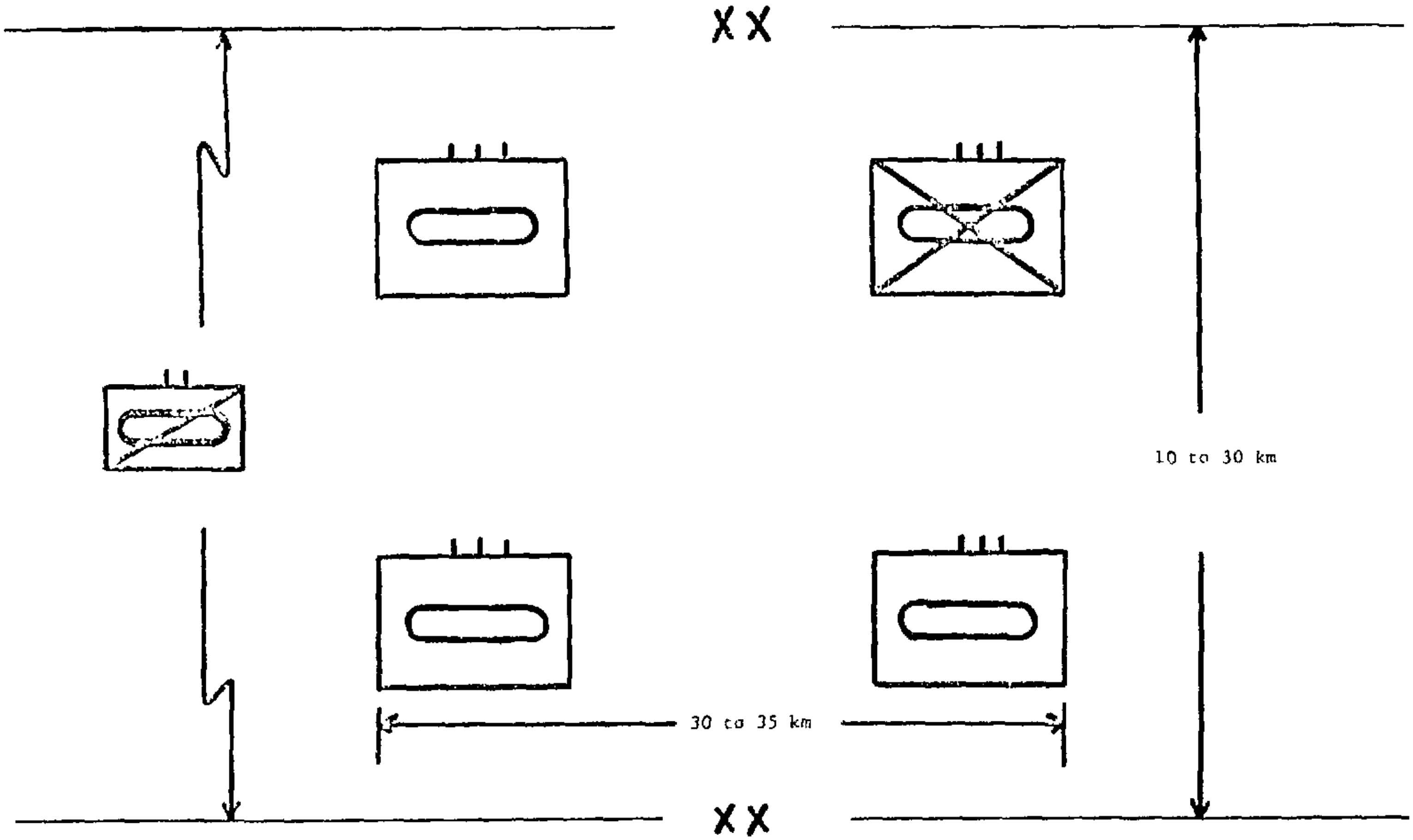

FIGURE 2. TANK DIVISION IN CAS FIRST ECHELON

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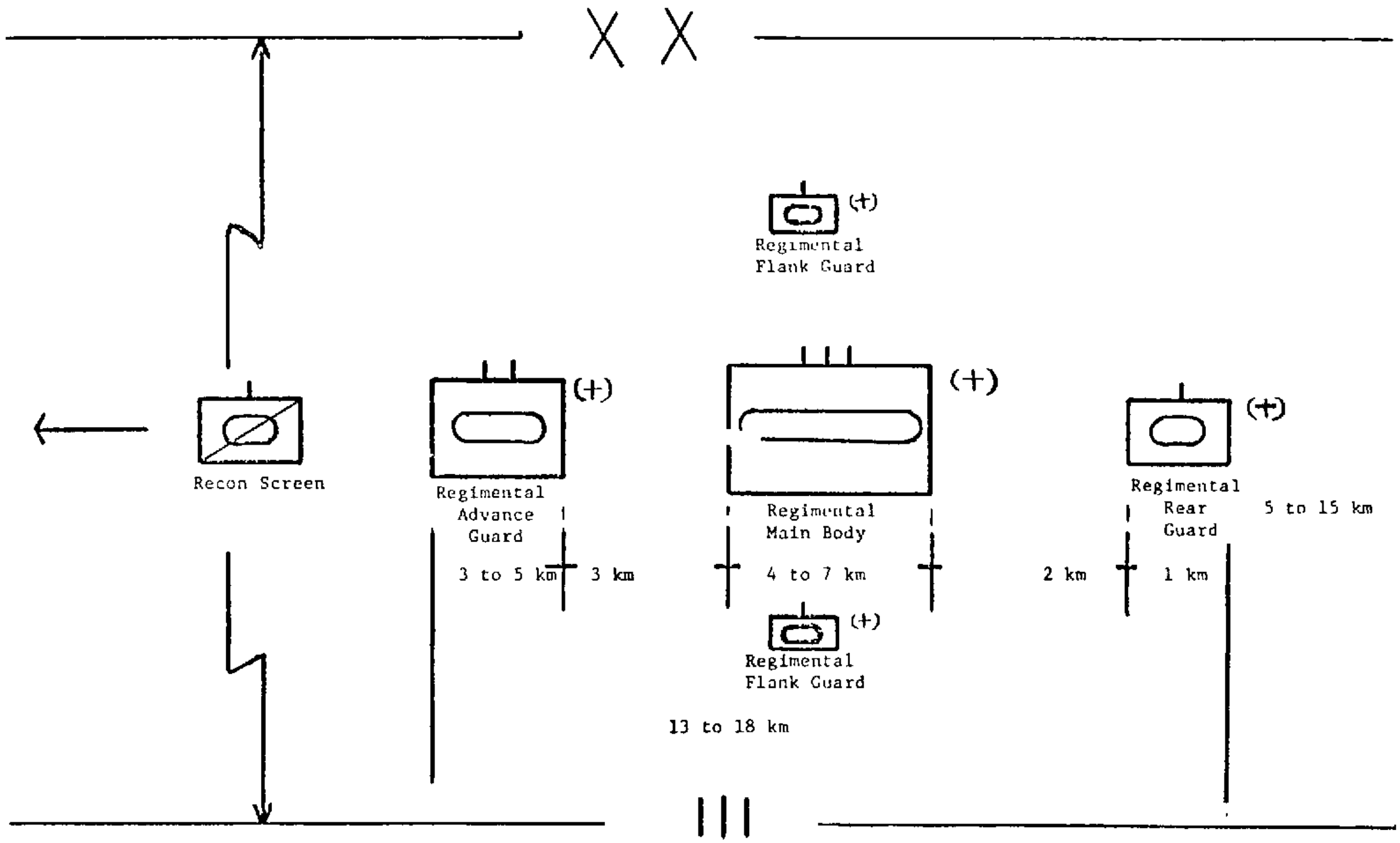

FIGURE 3. FIRST ECHELON TANK REGIMENT OF FIRST ECHELON TANK DIVISION
(ADVANCE TO CONTACT)

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2.5 Tank Battalion, Tank Regiment

The battalion headquarters has an extremely limited staff section to support the commander. Each tank company has three platoons of three tanks each, plus one tank for the company commander. One tank in the battalion headquarters gives the tank battalion a total of 31 tanks. The supply and maintenance platoon provides limited combat service support. The medical section provides an immediate first aid and limited evacuation capability for the tank battalion. The tank battalion has about 22 officers and 185 enlisted personnel.

3. OFFENSIVE TACTICS

3.1 General

Force superiority is the primary consideration in the attack. Main attacks made by regimental groups of 95 T-62 tanks supported by infantry in BMP's would not be uncommon. In close terrain, motorized rifle infantry battalions of the motorized rifle regiment would comprise the attacking force supported by the 40 tanks of the organic tank battalion. Surprise is the major factor in any plan of attack. It will be attempted in any of the following ways:

(a) By heavy, accurate, conventional, chemical, or nuclear fire.

(b) By concealing the force size and direction of attack. For example, a force will advance and maintain contact along a broad front but hold an attack formation dispersed in depth.

(c) By mounting diversionary attacks in other sectors.

(d) By excellent communications security.

When the opponent has established a defensive line that the Soviets cannot bypass, the first echelon force will attempt to break through the line, orienting the battle toward deep objectives in the opponent's rear rather than seizing and consolidating on shallow terrain objectives. The capture of strongpoints and key terrain is left to succeeding echelons.

Soviet forces normally try to mass so that they have at least 6 to 1 advantage in tanks, artillery and units. Threat attack tactics consist of a penetration of forward positions, seizure of deep separated objectives to trap and destroy the defender, and continuation of the advance.

3.2 Regimental Attack

A regimental attack will be organized in two echelons. The first echelon is that part of the combat units assigned responsibility for execution of the primary mission. The regiment's second echelon forces follow the same route of advance as the first echelon forces, but have secondary or follow-up missions that may be changed as the situation develops. Emphasis is on the combined arms team. Even in motorized rifle regiments, the thrust is on maximum use of tanks. Within a regiment, ADA priority is assigned to defense of command posts and tank units. Each maneuver battalion must be expected to have at least one ZSU-23-4. At times, such as when forced into a defense, the ZSU-23-4's may also be employed in a ground role against targets varying from tanks to dismounted infantry. Threat forces are well-trained in fighting at night and during

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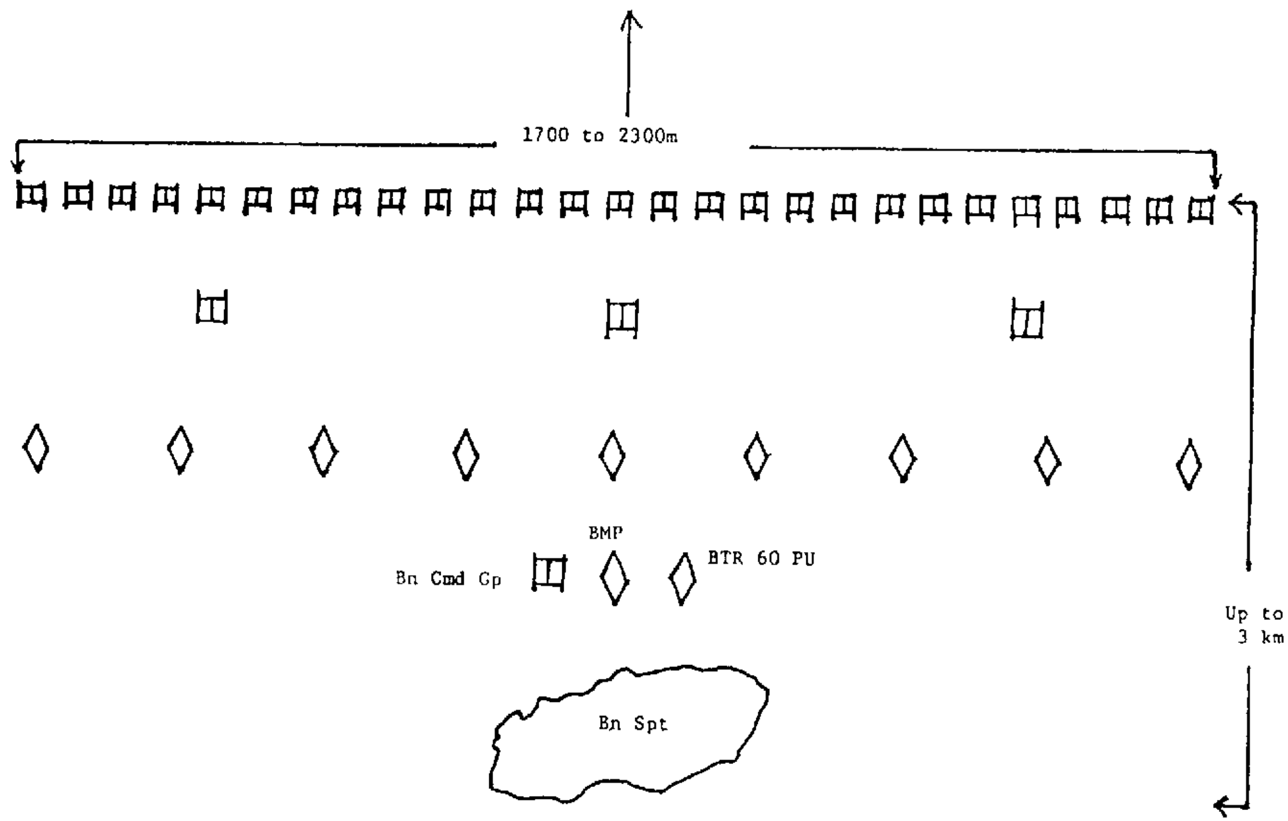

NOTE: Battalion may assault in two echelons, with two reinforced Tank Companies in the first echelon and one reinforced Tank Company in the second echelon.

FIGURE 7. TANK BATTALION (REINFORCED WITH MR CO)
CONDUCTING MOUNTED ASSAULT

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Factors favoring remaining mounted are:

- NBC Contamination
- Desert Environment
- Reduced Antitank Capability
- Weak Defense

Factors favoring dismounting the infantry are:

- Strong Antitank Capability
- Strong Defense
- Fords or Bridges
- Obstacles or Minefields
- No High Speed Exits
- Maximum Firepower Desired

Normally, the assault is led by tanks. When the decision has been made to dismount the infantry, the tanks will normally lead, followed by dismounted infantry and they will be followed by the BMP's. These three lines will not normally exceed four hundred meters in depth. When obstacles cannot be removed by mechanical means, the infantry and accompanying engineers will dismount and clear lanes through the obstacles, while under the protective fire of the tanks and BMP's. Once a lane has been cleared for each platoon, the tanks will pass through these lanes as fast as they can, and will be followed by BMP's. To regain lost momentum, the infantry will remount their armored carriers. Once the assault is successful, the units will consolidate and prepare to continue their mission. If the assault is not successful, they will assume a hasty defense and wait

for indirect fire support to degrade the defensive position further, while another unit enters into the fray. Dependent upon the degree of defensive resistance presented, the initial unit will continue to hold, pull back, or join in a massive breakthrough attempt.

3.8 Deliberate Attack

If the hasty attack fails, the leading elements will establish a hasty defense as close as possible to our defensive positions, and a deliberate attack will be prepared.

3.8.1 Preparation

The deliberate attack is normally launched by second echelon regiments or divisions and is covered by forces already in contact. The deliberate attack is preceded by a thorough reconnaissance with emphasis on finding our AT positions, and sufficient engineer work to clear lanes through enemy obstacles. The Soviet force considers finding and neutralizing our ATGM positions of utmost importance--one of the keys to launching a successful attack. The deliberate attack is preceded by a 25-minute intensive artillery preparation. The leading assault elements will move within 100 meters of this fire before it is shifted to targets farther to the rear. (Quick attacks are also preceded by artillery preparations, but the length and intensity of these preparations is governed by the number of artillery units in position to fire. Soviet forces will not delay a hasty attack to wait for artillery units to move into position.)

3.8.2 Assault

Tanks always lead the assault, firing the main gun and machineguns on the move. They will stop to fire from the short halt (4 - 8 seconds) if an important target is found. When a critical target is found (such as our tanks or ATGM firing positions), massed fires of an entire platoon, company, or battalion will be used to destroy these targets, with the firing unit firing until the target is destroyed. Tank and APC's, with infantry mounted, assault with tanks leading. Assault forces rely heavily on smoke to mask their movement. When facing heavy defensive fires, the tank company or motorized rifle battalion may resort to fire and maneuver techniques, though this is not their normal tactic. Fire and maneuver is not practiced lower than tank company. Generally, artillery, direct fires from the motorized rifle battalion, second echelon forces, and mortar fires are relied on to provide all suppressive fire. Second echelon forces may provide suppressive fires from overwatch positions.

3.9 Second Echelon Forces

Three to six kilometers behind the regimental first echelon is the regiment's second echelon. If the attack of the first echelon is slowed or unable to overcome our opposition, the second echelon attacks to attempt to push through or outflank our forces. If the regiment's momentum is still slowed, the division's second echelon will be committed to the attack. The main purpose of the second echelon is to build up the efforts of the first echelon and exploit success at high rates to a great depth. The second echelon of a motorized rifle or tank division consists of the remaining tank and motorized regiments. The second echelon is committed to maintain the momentum of the attack by:

- Reinforcing the first echelon.
- Conducting a flank attack.
- Reducing pockets of resistance.
- Blocking counterattacks.
- Bypassing to envelop a strong defensive position.

The tactics of using a second echelon is consistent throughout the Soviet ground forces; therefore, even when talking of *combined arms armies*, there will still be a second echelon. The distance between the first and second echelon depends on the tactical situation.

4. TRAINING

Soviet tank crews take part in tightly controlled training on both driving and firing ranges. The emphasis in driver/mechanic training is on safely overcoming a series of driving hazards within a set time limit and on driving in such a way as to present the gunner with a good target picture. The obstacles on a typical driving course will include hills, bridges, steep slopes, S bends, ramps, and a deep fording obstacle. Gunner training emphasizes accuracy with the main gun and machinegun while on the move as well as in place and from short halts. Loader training is less formal and covers loading duties and assisting other crewmembers in their duties. Tank commanders training includes the design of the tank, and its major components, rules for the employment of the tank in combat, maintenance, and storage procedures. In addition, the tank commander-trainee should learn to perform and organize the work of the other crew-members in technical servicing, eliminating defects, and in preparing the tank for snorkeling. Instruction in general subjects includes small arms marksmanship, driving, and radio communications.

Soviet field training encompasses both simulated nuclear effects, and exposure to actual chemical agents. Protective clothing may be worn for prolonged periods of time.

5. CRITICAL COMBAT TASKS

Based on a review of open source literature, the following are believed to be the most critical tasks performed by Soviet tank crews in an active nuclear environment, while conducting offensive operations:

- Maintain formation.
- Overcome obstacles.
- Acquire targets.
- Engage targets within 20 seconds or less with the correct ammunition.
- Adjust fire (if necessary).
- Repair malfunctions.
- Perform maintenance.

Although specific critical combat tasks for Soviet units in the attack is not available in open source literature, it can be concluded that they are similar for any armor unit regardless of nationality. The following general tasks apply in offensive operations:

- Move to contact in accordance with plans of higher headquarters.
- Maintain position in the attack plan (formation).
- Acquire targets.
- Control and distribute tank and antitank fires to efficiently service all targets.

- Efficiently employ all elements of the combined arms team (tanks, infantry, artillery, engineers, etc.) to maximize their particular capabilities.
- Coordinate maneuver and indirect fire support.
- Maintain communication.
- Maintain momentum of the attack.
- Provide timely combat and combat service support.
- Understand and execute changes in orders.

6. *POTENTIAL SOVIET VULNERABILITIES*

Shortage of combat veterans.

In training, when the code word "Atom" is announced over the radio, tank crews shut off their engines and don their protective suits and masks. In actuality, the engine can be shut off by a device which senses nuclear radiation. The device will activate twice, then a circuit breaker must be replaced. Extra circuit breakers are carried in the tank. Engines are restarted after the crews have donned their protective clothing. Prolonged wear of the protective suits can be quite fatiguing in warm weather. Trying to don a protective mask while vomiting can be a trying experience. Having a tank's engine shut off while conducting an assault, or negotiating a turn in mountainous terrain, can be hazardous.

When not expecting combat, Soviet tank commanders travel with their hatches open. This would probably occur in second echelon units.

During tank gunnery qualification, only the tank commander and the gunner fire service rounds. They qualify twice each year. The T-62 main gun cannot be fired from the tank commander's position. Accordingly, if the tank commander becomes a casualty, the tank gunner assumes command from his position. If the driver is killed, the commander drives and the gunner assumes command of the vehicle from his position. If the loader is killed, the commander becomes the loader and the gunner assumes command of the tank from his position. As a result of this shifting around, the tank crew is significantly less effective if only three men are manning the tank. Visibility for target acquisition is poor from the gunner's position and control of the tank is more difficult.

7. FUNCTIONAL VULNERABILITY OF TACTICAL MILITARY UNITS

7.1 Problem

At present, the effect of nuclear weapons on tactical targets is normally determined by calculating the fraction of an assumed target area that is "covered" by a designated level of nuclear damage to a selected element (e.g., personnel) of the enemy target. This element is assumed to be spread uniformly within the target area. The attack is judged successful if some arbitrarily selected fraction, usually 30 percent, of the target is covered with the desired level of damage. The document commonly cited as the reference for this number (ORO Technical Memorandum 289) clearly states that neither the number nor the concept are appropriate for this purpose. Various studies have used other percentages but with no more convincing a rationale. The need for an acceptable basis for estimating damage to tactical targets is widespread and pressing as evidenced by the inclusion of

fractional coverage defeat criteria in the official tactical target analysis system and in all major weapon system studies. The assertion is sometimes heard that such criteria are not important for actual warfare because after the first day everyone will know how many weapons to fire. This assertion seems diametrically opposed to the fact that we have fought many wars with conventional weapons and still do not have a credible criterion for conventional weapons employment.

The present method of evaluating the effects of nuclear weapons on tactical targets suffers from the following serious limitations:

(1) The attacker has no quantitative idea what an attacked unit will still be capable of doing or when it will be capable of doing it. This is a major problem because the analysis of a "destroyed unit" indicates that 70 percent of the unit's personnel and the vast majority of its equipment are not destroyed.

(2) No account is taken of the cumulative effect of "sub-criterion) damage to the element of the target that is being evaluated. It should be noted that the damage considered sufficient for a "kill" by conventional munitions (on the same battlefield against the same targets) is frequently considered inadequate for a nuclear "kill."

(3) No account is taken of the cumulative effect of the extensive damage to elements of the target other than the single one being evaluated. The combination of this damage and the "sub-criterion" damage to the element being considered could easily result in the

unit being functionally destroyed at levels below those required by present guidelines.

(4) No account is taken of the fact that although only a small fraction of the personnel in a given unit might have received a dose of radiation that produces immediate incapacitation, the vast majority of the unit personnel will eventually die.

Our present requirement for large yield tactical weapons is a significant consequence of the present approach to nuclear weapons employment based solely on individual target element response. An alternative method which takes into consideration the cumulative damage done to a target by a nuclear weapon would be very desirable from the standpoint of reducing required weapon yield. This, in turn, would greatly facilitate the use of tactical nuclear weapons.

7.2 Problem Solution

Application of the concept of functional vulnerability to tactical units could lead to significant improvement in the effectiveness of our use of nuclear weapons against tactical battlefield targets. This approach to weapons employment considers tactical units as integrated functional entities having identifiable subfunctions and interrelationships which contribute quantitatively to the accomplishment of measurable battlefield capabilities (e.g., accurate delivery of specified quantities of artillery in specified times). The total physical damage inflicted on a unit is interpreted in terms of degradation of the specific functional capabilities derived from the damaged element. The functional vulnerability concept produces damage assessments based on quantified degradation of specific

operation capabilities (e.g., firepower) of realistically-configured tactical units. By evaluating the units' capability to perform long sustained missions, the time-dependent effects of nuclear radiation and other latent effects are given proper weight.

The methodology for applying the concept of functional vulnerability has been demonstrated in the on-going comparative evaluation of nuclear and non-nuclear munitions. The basic steps of the procedure include:

- Identify the unit's mission(s) in terms of performance or required results.
- Determine the unit's components, organization, and functional relationships needed to fulfill its mission(s).
- Develop a quantified model of the essential elements and functions of the unit.
- Determine the physical damage inflicted on the essential elements of the unit in realistic battlefield deployment by the munitions of interest.
- Evaluate the functional consequences.

8. SUMMARY

The critical question in using radiation to blunt a Soviet armored assault is the effect of radiation on a well-trained team performing a difficult combat task. Most data available on radiation effects addresses the impact on individual humans or animals. Particularly in the case of animals, each is performing a relatively simple task. In an armored force, the tasks are immensely more difficult and at all levels require the interaction of groups of people as a team. The team can

be as small as 4 personnel in a tank crew or as large as 400-500 personnel in a battalion. The combined effects of blast, thermal and radiation increase the complexity of the problem. For example, within a tank crew of four men if one is totally incapacitated, two are operating at 70-75% efficiency and one relatively unaffected, we are unable to measure the degree of performance degradation or the point at which the tank is totally ineffective. Similarly, in a tank company or battalion we are unable to determine at what level of exposure the unit's ability to carry on with a demanding combat task ceases to exist. The critical tasks listed in Paragraph 5 must be performed continuously and some simultaneously; team coordination at all levels, crew through battalion/regiment and higher, is essential. The critical issue is that we are unable to determine at what level of radiation exposure the cumulative effects of deaths, incapacitation, and degraded performance, caused by vomiting, diarrhea and so on spread across the entire unit and breaks down the teams' ability to continue. Or, at what point the Soviet units' performance is degraded to the extent that their superiority in numbers can be overcome because their task execution is marginal. There are no data available on team response to the combined effects of incapacitation of a portion of its personnel and degraded performance by the majority of the remainder. These questions need answers. Future tests should be designed to provide insights into this area and should be given highest priority.

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